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REPORT ON THE WORK OF THE BARTOL RESEARCH FOUNDATION, 1935–36.*

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BY

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INTRODUCTION.

Again I find myself in my annual difficulty of knowing where to start. Last year I likened myself to a small child, who, when asked to play certain portions in the middle of her piece is unable to do so without going back to the beginning and playing the whole thing through until she arrives at the place where she has been asked to play. In order that my feelings shall not remain too much alike from year to year, in speaking of the work of the Bartol Foundation for the period 1935 to 1936, I liken myself to an operatic tenor who is asked to start in the middle of his high C, and sing only the latter half of the C, omitting the first half and the luscious (or nauseating) portamento by which he climbs to it. I fear I must again claim your indulgence, and beg of you to allow me at least my portamento to lead from the general discoveries in the physics of recent years to those which have concerned us primarily at the Bartol Research Foundation during the year which has passed.

Our investigations for the last year have centered for the

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most part upon problems having to do with the various phases of nuclear physics. Again I remind you that just as in our modern civilization, the things which we use are made for the most part of certain standardized parts which are the same for all, just as the battleship and the skyscraper have in the ultimate details of their construction, bolts of the same types and sizes and screw threads, nails of the same length and diameter, so in the much more complicated structure which is the universe as a whole, the Grand Architect thereof has anticipated by many eons the principle of standardization which the modern engineer has set as his ideal for construction; and, in the relatively few different kinds of atoms extending in weight from hydrogen the lightest to uranium the heaviest, we find the standardized parts out of which everything in our universe is made. But these standardized parts themselves are made up of a fewer number of still other standardized parts which indeed are the same for all of the atoms. The first of these standardized parts to be discovered was the electron, the natural unit of negative electricity. Soon after came the proton. The natural evolution of our thought from a form appropriate to the physics of the middle of the last century led us to think of light and heat, and of all radiations of that kind, as of a wave-like type in which the waves spread throughout the universe. The idea of individual particles associable with the different colors of the light was foreign to our whole mode of thinking; and the acceptance of any such ideas was resisted to the last ditch by our mid-Victorian physical instincts, until the discoveries of the new century, growing with ever increasing abundance, forced us to a revolution in thought in which we came to realize that light itself must be regarded as composed of a number of individual entities or quanta as they are sometimes called, each of these quanta being associated with a definite color of light, a color characterized by what the wave-length would have been upon the older line of thought. This principle ramified beyond the range of the light rays which affect our eye into the range of the ultraviolet light, then into the range of the x-radiation, then into that of the gamma rays from radium, and finally to those radiations of extremely high energy which are to be found associated, in part at any rate, with cosmic ray phenomena.

This whole class of rays extending from wireless waves through heat rays, light rays, ultra-violet rays, x-rays, gamma rays, to the rays associated in part with cosmic rays, this whole class of rays which in mid-Victorian physics would have been thought of in terms of waves in an all pervading ether has been segregated off by itself to distinguish it from rays which consist of material particles like electrons, protons, and atoms; and the members of this more ethereal class are called photons.

Photons having been accepted into the realm of physical thought, again, the hope was to explain all nature in terms of electrons, protons, and photons. Within the last two or three years, however, other fundamental entities have made their appearance. The positron, the positively charged counterpart of the negative electron has come out of hiding. A neutral particle, the neutron, an uncharged particle as heavy as the hydrogen atom, has come to light. A mysterious kind of a ghost, the neutrino, which has appreciable mass only when it moves, has been heard, as it were, rumbling about inside the atom. Then there is the atom of heavy hydrogen, the deuteron, which is associated with what is more popularly known as heavy water. With the appearance of all these new entities has gone, hand in hand, the growing feeling that all are members of a family whose relations to one another are closely bound up in a way which science may some day reveal.

Our views as to the nature of the atom have undergone considerable development in recent years; but such changes in our pictures as have taken place have left unaltered one fundamental idea. That idea is to the effect that an atom is composed of two parts—a central part called the nucleus which contains all of the positive electricity, some electrons and possibly neutrons, and which is responsible for practically all of the mass of the atom; then around this nucleus we have a few electrons performing a kind of dance, a dance whose form is controlled by the nucleus which sits there at the center as a sort of massive atomic chaperon. We can influence the dance of the outer structure by our experiments; and in our power so to influence the dance lies all the science of chemistry, all the phenomena of optics, of x-rays, and most of the things

which have interested the student of natural philosophy for several decades. Until comparatively recently we were unable to do anything to the nucleus. It was the nucleus which distinguished one atom from another. The lightest atom, hydrogen, has a simple nucleus comprising nothing more than one proton. The next lightest atom, helium, has a more complicated nucleus, and has in all a positive charge equal to that of two protons. As we arrange the atoms in the order of their weight, their nuclei become more and more complicated in structure. Each successive element in the ascending scale, however, differs from its predecessor in having one additional proton's worth of charge. It is this charge which determines the power of the nucleus to influence the dance of the outer structure.

I have said that until recently man-made experiments were unable to bring about any change in that firmly built structure, the nucleus. That such changes were not fundamentally impossible was evident from the fact that some of the atomic nuclei, those of radium, for example, were known to blow up spontaneously of their own accord from time to time. Within the last two or three years, the man of science has been preparing his artillery for the bombardment of the atomic nucleus, with a view to realizing, in actuality, the age old dream of the alchemist, the transmutation of the elements. The projectiles of his artillery have been those particles, the electrons, the proton, and so forth, of which I have already spoken. For many years he has been studying the characteristics of some of these projectiles, the electron, for example. When we seek to know the nature of such elusive invisible things, it is necessary to proceed according to Biblical instructions, "By their fruits shall ye know them," and so we must judge of these things by what they can do.

Electrons and positrons when fired through the atmosphere, for example, possess the power to kidnap electrons from the outer structures of the atoms by which they pass. Their influence extends some distance on either side, and they, as it were, tickle our participants of the dances in the various atoms near which they go. Ordinarily they do not do anything very drastic and are relatively easily turned from their paths. Heavier particles like the protons, however, when

endowed with sufficient energy possess the power occasionally to run headlong into the nucleus of the atom, knock out some of its parts and result in its becoming another kind of atom. The atom of heavy hydrogen when used as a projectile is a still more potent means of producing nuclear disruption. The neutron, which we sometimes think of as an electron and a proton in close communion, when traveling through the atmosphere, for example, pays very little attention to the dancers in the outer structure of the atom. His two parts are too much occupied with each other to give much attention to trivial activities encountered on the way. The neutron, however, is a dangerous fellow even with comparatively little energy, and by the very fact that he produces but little disturbance in the dancers around the nuclei of the atoms, he is able to make entry to those nuclei and then like an insidious agitator whose silent and unobtrusive manners have enabled him to inveigle himself into the very heart of the atomic government, he is able to promote such disturbance of the governmental equilibrium, by claiming accommodation, as to set up a situation in which nothing but an atomic revolution can straighten matters out. Thus, the neutron is able to initiate the formation of new elements by promoting atomic explosions with the emission of all sorts of projectiles analogous to those brought into evidence in a real honest-to-goodness revolution in the affairs of mankind.

The neutrino is a mysterious kind of thing. He has never been found actually doing anything, and his presence has been inferred on the basis of the same kind of evidence which, when strange things happen in an organization, prompt one to say, "Somebody must have been at the bottom of that."

At the Bartol Foundation, we are at present developing our plans for building a cyclotron. This is an apparatus for the purpose of endowing particles with very high energy such as is necessary to bring about atomic disintegration. Such apparatus now exists in many of the prominent research laboratories in this country, particularly at the University of California where Professor Lawrence has developed what is probably the most efficient of all these appliances of what we may call man-made artillery for bombarding the nucleus of the atom. Pending the construction of this piece of atomic

ordnance, however, we have busied ourselves with certain other aspects of the problem which are as necessary to the successful prosecution of this war on the atom as the problems of the commissary department are necessary in wars having to do with the affairs of men.

RESEARCHES ON GENERAL NUCLEAR PHYSICS.

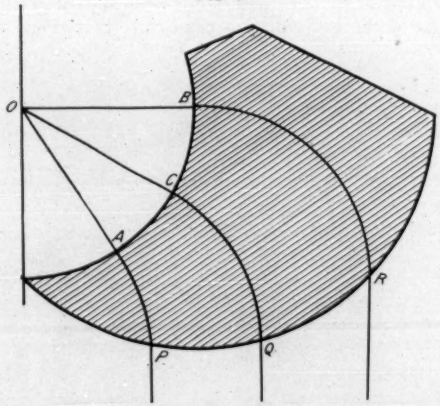
Isotopes and Their Separation in Large Amounts.—Suppose we have two identical atoms and then add to the nucleus of one of them a neutron, or a positron plus an electron. Suppose, in fact, we add any entity or combination of entities which as a whole carries no electric charge. Then the altered atom will differ from its companion simply in the weight of its nucleus. The charge on that nucleus will be the same for both atoms; and, as far as chemistry is concerned, and as far as most of those phenomena having to do with the outer structure of the atoms are concerned, the two atoms will be exactly alike. Atoms differing from each other in this way are called isotopes; and, as you will recall from my former reports, a goodly portion of our knowledge regarding them has come from the work of Dr. Kenneth Bainbridge, performed at the Bartol Research Foundation in years gone by.

Now the elements as they usually present themselves to us are mixtures of such isotopes; and, in the study of the nuclei of the atoms, it is desirable to deal with what we may call the pure atoms, the individual isotopes themselves. Unless we do this, we are without an exact knowledge of the things upon which we are working. It is for this reason that, during the last two or three years, Dr. Rumbaugh has been concerned with the perfection of apparatus whose purpose is to separate some of the isotopes of the elements in amounts sufficiently large to permit of the actual use of the individual isotopes in experiments. Within the last year, Dr. Rumbaugh's investigations have been crowned with their first stages of success, and about four milligrams of the two isotopes of lithium of relative weight 6 and 7 have been separated. The condition of the apparatus at the present time is such that it is possible to separate into its two isotopes about 0.1 milligram of lithium per hour.

I must pass very briefly over the method adopted. It will

suffice to say that a lithium compound is embedded in a silicon carbide rod from which it can be evaporated. Under these conditions a certain fraction of the evaporated atoms exists in the charged state as a result of the removal of electrons from their outer structures. A wide beam of these atoms is shot away from the source under the influence of an electric field and the beam is caused to enter the space between the two poles of a magnet. Figure 1 shows a section of the pole

FIG. 1.

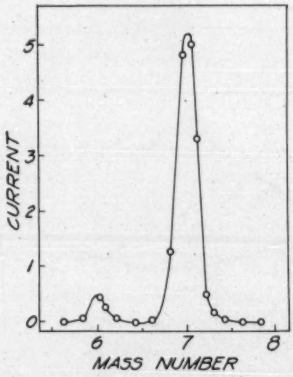


space. Now when the charged atom, ions as they are called, travel across this pole space (from below, in the diagram) their paths are bent, to an extent depending upon the mass of the atom concerned. The atoms at the right of the beam as represented in the figure have to travel a greater distance under the magnetic influence than do the atoms at the left portion of the beam, the pole space being in fact fashioned to a suitable shape so as to result in such a condition. The result is that the right and left lines of particles originally parallel in their flight are no longer parallel, but are directed so as to converge to a point. By suitable choice of the shapes of the pole pieces, it is possible to bring all of the ions in the beam to the same point, or rather to a point which is the same for

the isotopes of one mass, but is different from that for the isotopes of another mass. The result is that we can separate the isotopes into two parts.

While the whole process is very simple in principle, a great deal of development is necessary to secure a satisfactory separation, and to produce a sufficiently copious supply of the ions. A process is necessary which will stand the high temperature required without distortion of the source. Great attention must be given to the correct shape of the pole pieces, and allied parts, so as to result in a sufficiently accurate concentration of the individual isotopes at their respective foci.

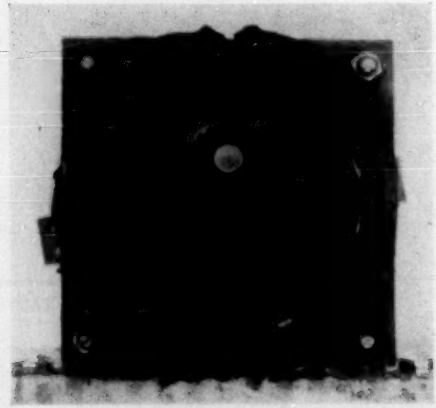
FIG. 2.



The isotopes may be made to announce their arrival at their destination by causing them to fall upon a little plate which is connected to the "ground" of the apparatus through a galvanometer. The charges from the isotopes passing through this galvanometer cause a deflection which is a measure of the rate at which the isotopes are being deposited at the particular point which the little plate occupies. By altering the magnetic field or the electric field which gives the ions their velocities, different isotopes may be caused to fall upon the plate. The electric field necessary to bring any given isotope on to the plate is characteristic of the isotope. In actuality,

two fields characteristic of the isotopes 6 and 7 were found to produce a focus on the plate. By making measurements for different accelerating electric fields it is possible to obtain data from which we may plot a curve such as Fig. 2, in which abscissæ represent isotope masses and the ordinates represent galvanometer currents, which currents are proportional to the rate of deposition of isotopes falling within a certain small range of masses determined by the size of the plate and centering around the corresponding value of the abscissa. It will be seen that there are two peaks corresponding to the isotopes

FIG. 3.

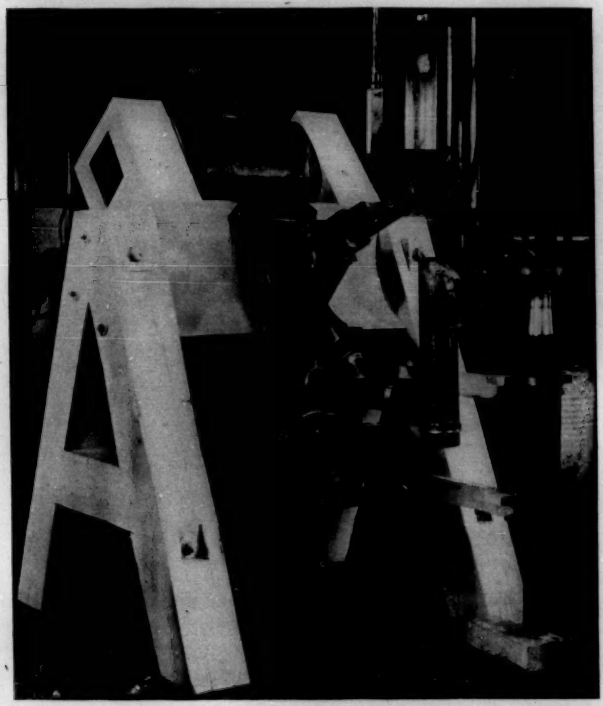


of relative masses 6 and 7. It turns out that the areas under the peaks correspond very approximately in relative value to the amounts of the isotopes 6 and 7 deposited in equal time. From this curve we therefore learn that the amounts of 7 and 6 deposited per hour are in the ratio of 12 to 1.

By replacing the electrode for the electrical measurements by two flat-ended metal tubes placed in the appropriate positions to receive the isotopes, it is possible actually to collect the isotopes in visible form. Figure 3 shows by the two spots, indicated by the arrows, the deposits of the isotopes 6 and 7 of lithium. Figure 4 is a picture of Dr. Rumbaugh's apparatus.

Dr. Rumbaugh is at present engaged in collecting the isotopes on a surface of convenient form to permit its use in subsequent experiments upon the disintegration which may

FIG. 4.



be produced in the isotopes when bombarded with protons, deuterons and neutrons.[1] He has also made considerable

[1] Since this was written, experiments upon the disintegration of the isotopes by proton and deuteron bombardment have been made and published (L. H. Rumbaugh and L. R. Hafstad, *Phys. Rev.*, **50**, 681 (1936).

progress towards the deposition of the isotopes of potassium in large amounts.

Experiments on the Creation of Matter from Energy.—One of the most profound generalizations of modern physics is the recognition of the relation between mass and energy, a recognition of the fact that when mass as such disappears, energy appears in proportional amount. Perhaps, in a sense, the usual form of statement of this principle is a little unfortunate because, in reality, mass never disappears. The energy into which it seems to be transformed itself possesses a mass, in all relevant matters, equal to that which seems to have been lost. Again, when energy is said to be transformed into matter, the matter itself really possesses the energy in special form. The significant thing about the change which we talk of as the change from mass to energy and vice versa is the change in characteristics of an entity subject to the condition that in that change something is preserved, that something being the mass, or the energy, whichever we like to specify. I should like to cite an analogy which I think will be helpful although I do not wish to invite a controversy which might follow from the analogy being taken too literally. We can think of the universe of living beings with unchangeable entities which we call souls; and, we can think of these beings as existing in two forms, the material form familiar to us within the realm of our mortal lives, and the spiritual form which comprises all those who have died or have not yet been born. The material beings, ourselves, have certain characteristics. We build ships, we make railroads, we fight and play. Those who meditate upon the denizens of the spirit world like to think of the spirits as doing other things, things which would be as strange to the category of activities of mortal beings as would be the setting up of a ten cent store by an angel. The spirits and the material beings all form part of one great universe, each group being perhaps necessary for the proper functioning of the other. If we think of a mortal changing to a spiritual existence by death, or of a spirit taking on mortality in birth, the identity of the soul being always preserved, we have an analogy to what is going on in the realm of the atom today, except that the thing whose identity is preserved in the change is that which we call the energy, or its

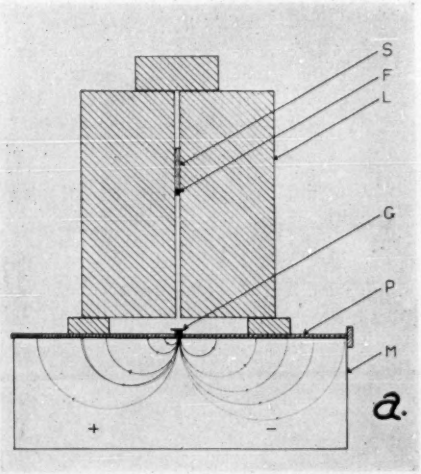
equivalent, the mass. To make the analogy more complete, I should have to ask you to suppose that a single soul can occasionally breed two bodies, and two bodies can occasionally become a single soul. There is a thought for the romantic to become poetic about. It represents the fact that in physics, a photon occasionally becomes transformed into a positron and an electron; and, conversely, a positron and an electron occasionally unite in pairs to form a photon.

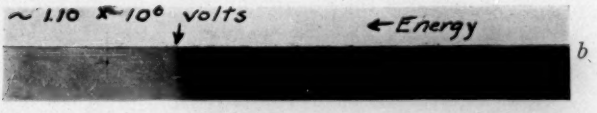
The equivalence of mass and energy, sensed first theoretically by Einstein, received one of its most convincing experimental proofs at our laboratory in the work of Bainbridge, who showed that when a lithium atom becomes wedded to a proton in such a way as to produce two atoms of helium, the combined mass of the two atoms of helium does not equal that of the lithium atom plus the proton. It is found, however, that the helium atoms produced possess kinetic energy; and it is necessary for the proton to possess kinetic energy in order that the transformation from lithium to helium may be realized. Bainbridge found that when due account was taken of the masses associated with the kinetic energies of the proton and of the helium atoms, the books balanced. The sums of the masses and of their energy equivalents calculated before and after the transformation were the same. Now in this experiment of Bainbridge, the energy whose mass equivalent was studied was the kinetic energy of the particles. We may regard it as a form of energy which is bound to the material existence of the particle. It is like a soul bound to the flesh. What becomes then of the equivalence of mass and energy when the energy produced is no longer associated with any material particle, when it is in a form such as light, or x-rays, when, in fact, it is in the form of a photon? In our analogy, what happens when the mortal being is changed entirely into a spirit? Dr. G. L. Locher and Mr. C. L. Haines, also of the Bartol Research Foundation, have recently performed an experiment to settle this matter; but they have attacked the question from the reverse end. They have started with the spirit, and have produced a materialization. The spirit was a gamma ray from radioactive material. The materialization of the spirit was a pair of particles, a positron and an electron. I have already reported briefly upon this

investigation in my report of last year. Since that time, however, further progress has been made.

Briefly the procedure adopted by Dr. Locher and Mr. Haines was as follows. The gamma rays from a radioactive source passed through a sheet of metal at *F*, Fig. 5, and it was

FIG. 5.





in this sheet of metal that the materialization to particles occurred. These particles passed down in a more or less vertical direction. On emerging from the point *G* they passed into the space between two large magnetic poles. The paths of the particles when entering this region of magnetic influence are bent into several paths, the positive particles being bent

one way and the negative particles the other way. If all of the positive particles had one definite energy and all of the negative particles another definite energy, we should have just one line for the positive and one for the negative on a photographic plate placed suitably in the place containing the points G and P. We have reason to suppose, however, that kinetic energy is shared between the positive particle and its partner to different extent by the different pairs of particles, so that we may expect, and we find, a distribution of blackening of the plate. However, the higher the energy of the particle the greater the diameter of its circle; and we should expect that no negative particle, for example, could attain a kinetic energy greater than that in which its partner had no energy at all except that used in actually creating it. We should therefore expect that on the negative and on the positive sides there would be upper limits to the blackening, one limit characteristic of the negative particle having all of the kinetic energy and the other limit characteristic of the positive having all of the kinetic energy. As a matter of fact there are certain complicating features which prevent the occurrence of that limit in the case of the negative particles. These I need not refer to further than to remark that they are concerned with electrons not created by the gamma rays, but hurled out of atoms by them in their passage through the metal. It is a fact, however, that we do obtain a definite limit of blackening in the case of the positive particles; and Dr. Locher and Mr. Haines found that the kinetic energy corresponding to that limit when subtracted from the known energy of the gamma rays which initiated the experiment gave a difference which was equal to the energy necessary to create the positron and the electron according to Einstein's mass-energy law. In Fig. 5, the arrow shows the limit referred to.

Now, as is apt to happen in physics, some of the most interesting consequences of a verification of a fact of this kind arise from the fact that the verification is almost exact but not quite exact, and the lack of exactness tells the story of something else. The verification of the law which Dr. Locher and Mr. Haines have produced is to within about 4 per cent. When, however, they take into account the accuracy of the various quantities which have entered into their calculation,

they are unable to see any place where they or anyone else whose data they have used could have made an error of as much as 4 per cent. It seems as though something else must have happened. The discrepancy is in such a direction as to indicate that the amount of energy observed after the process is less than what is to be expected. There had been a kind of tax of energy in the process; and Dr. Locher and Mr. Haines are now inquiring why the process appears to be taxed.

If there is a tax on the process, one might suppose that the atom which was hit by the original gamma ray, and which was responsible for irritating it into a materialization in the form of a positron and an electron would have something to say about the matter. One might think that perhaps the atom charged a commission for its activity and that this represented the tax. For this reason Dr. Locher and Mr. Haines repeated the experiment using a different type of metal to initiate the process. In the first experiment they used lead and in the second experiment they used silver. However, in both cases the results were the same, so that if the tax has to do with the atom, it has been standardized for all atoms, or at least for the two which have been tried. The story of the whole matter is, however, complicated by certain other considerations. When we look closely at the photographic blackening represented in Fig. 5, we find indications of certain other bands in the blackened region. These are too faint to show in the reproduction but they are unquestionably there. The first thought is that they correspond to the story of the creation of positrons and negatrons initiated by some of the gamma rays from the radium other than those which figure in the main process. There are such gamma rays. It is found indeed that some of the bands do correspond to the position to be expected on this idea, at least approximately, but again there is a slight discrepancy of the order of a few per cent. Now if this few per cent. represented a tax demanded by the atom, we should expect that the tax would form the same percentage of the transaction for all of the gamma rays; or, even though we should not demand as simple a relation as this, we should at least demand that the tax was always a tax, never a credit. It would appear, however, that sometimes the discrepancy calculated on the basis to which I have referred appears as a

credit instead of a tax. Well, these matters are in the process of investigation; and it is impossible to say any more at this time. Possibly next year we shall have something more to say. As matters stand at present we may say that the mass energy relation in this particular phenomenon has been verified to a reasonably high degree of accuracy but that there are some minor discrepancies which when completely explained will probably give us still more interesting information on the nature of this fundamental atomic process.

Experiments with Neutrons.—As a preparation for the time when we may have available the copious sources of atomic projectiles provided by the cyclotron, Dr. Locher and Dr. Rumbaugh have taken advantage of the opportunity provided through the courtesy of Dr. G. M. Dorrance of using the gamma rays from the four grams of radium at the Oncological Hospital. They have allowed these gamma rays to fall upon beryllium; and, under these conditions, as is well known, neutrons are produced. They have been studying some of the properties of these neutrons as disintegrators of atoms. As I have already remarked, neutrons differ from high energy charged particles in their method of producing atomic disintegration; for they are more potent in their activities when they have but little energy. Since the neutron carries no charge, it is not possible to produce, control, and determine, its energy by such processes as we can produce, control and determine the energy of charged particles. We have to take what energy nature gives us and then alter it by tiring the neutrons out, by allowing them to pass through some suitable substance, such as paraffin, in which they lose some of their energy. Unfortunately if we allow even a homogeneous beam of neutrons to pass through an appreciable thickness of paraffin the beam becomes terribly heterogeneous because different neutrons lose different amounts of energy. Moreover, many of them are scattered in all sorts of different directions. The greater the thickness of the paraffin, the more mixed up is the scattered beam of neutrons which gets through it. Nevertheless it is of very great importance to investigate the potentialities of the neutrons for producing atomic disintegration as a function of their energy. Such investigations have been carried out by others in the past and Drs. Rumbaugh and

Locher have been extending these investigations principally in the direction of using gamma rays as a means of producing the neutrons instead of high energy nuclear particles from radioactive sources or high voltage machines. The neutrons produced by gamma rays have lower energy than those produced otherwise and so the thickness of paraffin necessary to reduce them to still lower energy is less. As a consequence, the story to be told becomes more definite. Using these exceptionally low energy neutrons it is the purpose of Drs. Locher and Rumbaugh to investigate their relative potentialities for producing disintegrations in various elements.

INVESTIGATIONS ON COSMIC RAYS.

I now turn to the story of our investigations during the past year on the subject of cosmic rays. As you will recall, these rays consist of high energy particles of some kind coming to us from outer space and entering our atmosphere in all directions. These particles create other particles in the atmosphere as they pass through; and the story of how far the things that we measure in our laboratory are the effects of these secondary particles and how far the story is that of the primary particles is a subject of great interest and complexity, and is one of the matters which has concerned us at the Bartol Foundation.

On every occasion on which I have reported upon this subject I have shown you demonstrations of the existence of these rays by the use of what are called Geiger Müller counters. Our technique in these matters has naturally improved as time has gone on, so this evening I am able to show you an experiment which is probably more clear cut than any I have shown before. As you will recall, a Geiger Müller counter is a little metal tube with a wire going down the center. Between the wire and the tube there is a battery whose voltage is just insufficient to cause an electric discharge through the gas between the tube and the wire. When a cosmic ray passes through one of these tubes it precipitates the catastrophe of a discharge and the electric surge in this discharge may be amplified by suitable devices so as to cause it to perform any act we wish. Here I have a group of such counters arranged in

a plane area.[2] Every time you hear a click, that means that a cosmic ray or some other kind of ray capable of setting one of these counters off has passed through this area. These rays come from all directions. By having two such areas of counters, parallel to each other, one above the other, and arranging the electric circuit so that the assemblage will only record when at least one counter in the upper area and one counter in the lower area discharges, we know that what the apparatus actually records is representative of rays which have come in those directions which permit the rays to pass through the two areas. In other words the apparatus acts as a kind of telescope. The telescope is now vertical and the rays which it is passing are recorded upon the face of this dial. We will count the number of them occurring in a minute.[3] Now let us turn our telescope at 45 degrees to the vertical and again count the numbers in a minute. Let us now turn it horizontally and do the same thing. You will see that the intensity of the rays varies with the direction to which the telescope is pointed in the sky. The fall off of intensity with increase of angle from the vertical is very largely due to the fact that the inclined rays have passed through so much greater a thickness of the atmosphere and consequently are reduced in their intensity for that reason.

Protons as Cosmic Rays.—I have already stated that a matter of fundamental interest is concerned in the question as to the nature of the primary cosmic rays. For reasons concerned with the way in which the cosmic ray intensity varies with latitude certain investigators, particularly Professor A. H. Compton and Dr. H. Bethe, have been led to propose that the primary cosmic rays in the vicinity of the earth contain an important contribution in the form of protons in addition to positrons and electrons, while in the upper regions of the atmosphere, alpha particles also play a significant part.

[2] The area comprised 27 counters occupying a total area of 600 square centimeters arranged to operate a dial and also to produce a sound when any one of the counters discharged. The area by itself gave rise to about 25 clicks per second, about one-third of which were caused by cosmic rays.

[3] The upper area was the 600 square centimeter area referred to under (2). The lower area occupied 250 square centimeters. The two areas gave about 20 coincident discharges per minute when arranged vertically, 16 discharges per minute when at 45°, and 3 per minute when the axis was horizontal.

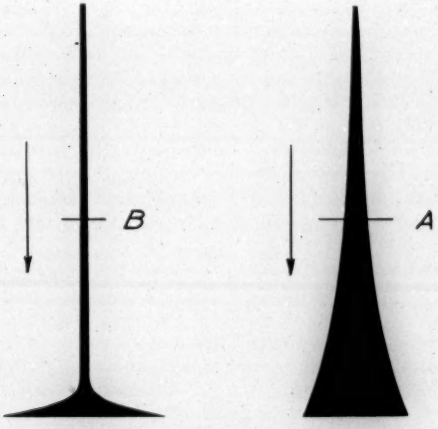
I shall presently discuss the question of alpha particles in the stratosphere. As regards protons at sea level, how are we to find whether or not they are there? The problem is to distinguish them from other charged particles and particularly from electrons and positrons. Now unfortunately protons, electrons and positrons all behave in exactly the same way as regards the ionization they produce in the atmosphere or in anything else when their energy is very high, as high, for example, as the energies which occur in cosmic ray phenomena. For this reason it is difficult to distinguish between them. For each of them we may say, "By their fruits shall ye know them," but their fruits are the same. It is quite true that the proton has 2,000 times the mass of the electron when both of these particles are moving slowly; but, unlike people, charged particles take on weight when they move; and high energy particles take on so much weight that the weight they had initially is negligible compared with the weight they take on. The corpulent proton and the skinny electron both grow to elephantine mass when they acquire great energy. The secret of the problem lies in catching them in their activities in a state of low energy, so that we may distinguish between them.

To cut a long story short, every high energy charged particle in traveling through the atmosphere has the same general kind of history. When its energy is high, that is when it is traveling with great speed, it passes by the molecules on its way very rapidly. The impulses which it gives to those molecules are of short duration and relatively few of them succeed in ejecting electrons from the atoms with the resulting production of ionization. In fact a high energy electron produces about 30 ions per centimeter of its path in air at atmospheric pressure. When a particle becomes reduced in energy and so in velocity, it becomes a much more efficient ionizer, so that it produces more and more ions per centimeter of path until it has lost all of its energy and has become dead as far as its activity is concerned. The charged particle is like an old man who when he has come near the end of his tether has a good old bust up before he dies.

Now consider an electron and a proton. As I have already said, when they have high energy they behave alike. Let us

consider them in a state where their velocities have fallen to a point where the mass which they have acquired on account of their velocity is not all important. Let us consider them in a state of velocity where the proton *knows* that it is 2,000 times as heavy as the electron. If both particles are traveling at the same *velocity* they will produce the same number of ions in traveling through a centimeter of gas. Each will lose the same amount of energy in producing these ions. This loss of energy will mean much more to the electron than to

FIG. 6.



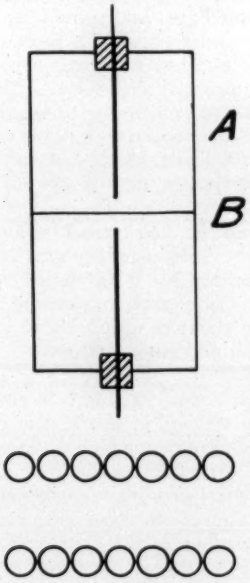
the proton, however, on account of the great mass of the latter. The result is that the period of high ionization will be much more extended for the proton than for the electron. If we should draw two lines whose widths represented the intensities of ionization by the proton and the electron, for example, those lines would look something like Fig. 6, where the particles are supposed to be traveling in the directions of the arrows. Although the ionization of the electron increases enormously towards the end of its range, the total number of ions produced in the whole of this region of high ionization

would be too small to observe except with the most delicate apparatus. With the proton, however, the situation is different. The total number of ions produced in the region of high ionization is quite large. In fact, the length of path in which the ionization is large is sufficiently great to permit us to pick out a small portion of it and even measure the total spurt of ions produced in that small portion. The situation is, in fact, as follows. Suppose that we make a little vessel, fill it with compressed gas, and provide it with the necessary appurtenances to render possible a measurement of the ions produced by a single ray in passing through it, provided that that ray ionizes sufficiently copiously. The theory of ionization by these particles enables us to measure back from the end of the range of the proton to a point where the ionization along the path, while less than that at the very end, is nevertheless sufficient to insure that if we put the vessel on the path at that point in question, for example, at A, Fig. 6, the ionization produced in the vessel would be measurable, although it would be immeasurably small for the corresponding position represented by B on the electron path. If R is the distance from our vessel to the end of the range then we know that all of the rays which, passing through a definite length in the vessel, end their paths within a distance R will produce at least enough or more than enough ions to be measurable as a distinct spurt of ions in the vessel. Now the number of rays so ending in the distance R is exactly the corresponding number of rays which by counter measurements we would find as absorbed in the distance R; and if we assume that all of the rays are protons we can find from the way in which our Geiger counter measurements change with altitude, how much this number is. If our measurements on the spurts of the ions in this vessel give less than the number to be expected, it means that protons are insufficient in number to account for the Geiger counter measurements and to just that extent.

In actually carrying out the experiment, certain precautions must be attended to. Thus, alpha particles from radioactive contamination in the walls of the vessel can masquerade as protons by giving large spurts. We can eliminate these by having a vessel such as A, Fig. 7, divided into two parts

by a partition *B*. A very thin partition will prevent the passage of contaminational alpha particles. Hence, if we take cognizance of only those spurts which occur simultaneously in the upper and lower halves, we shall omit from consideration all of the spurts due to alpha particles. There may still be certain spurts of ions produced by atomic bursts

FIG. 7.

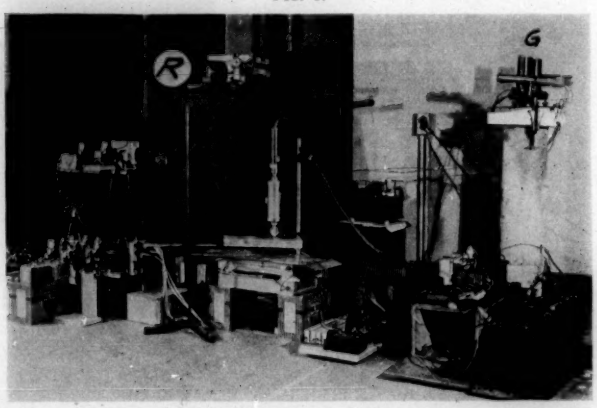


or showers of many electrons originating in the upper parts of the chamber or elsewhere. To eliminate these we set up an area of Geiger counters below the vessel, and so arrange that each area of counters will only make a record if two or more of its members experience the passage of a ray. Under this condition the Geiger counters will respond to electron showers but not to individual protons. By such a procedure

we can disentangle possible effects of protons from the other complicating phenomena.

The foregoing experiment is now under way in the hands of Dr. and Mrs. Montgomery, Mr. Ramsey, and myself. The data so far obtained indicate that the number of spurts observed and attributable to protons are so few as to necessitate the assumption that only a small fraction, if any, of the cosmic rays observed at these altitudes are representative of protons. A picture of the apparatus is shown in Fig. 8 and will be clear from the legend attached.[4]

FIG. 8.



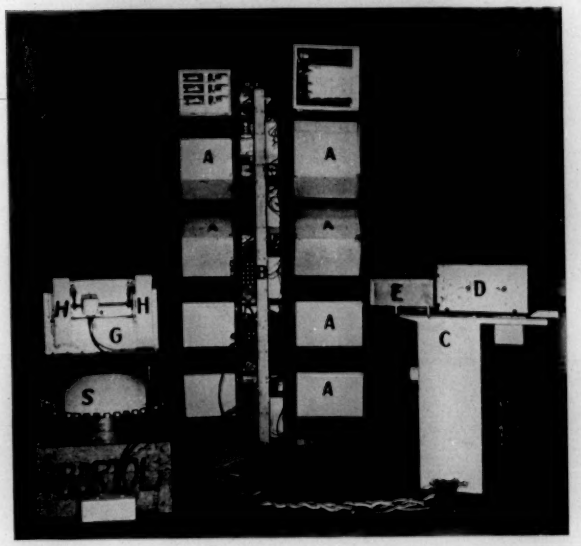
The vessel *A* of Fig. 7 is shown at the center of the picture fastened to the bottom of the tube which is held in a clamp. This tube and another horizontal one like it below the ionization vessel hold the pliotrons used for recording the spurts of ions. The counter sets are immediately below the above named apparatus. The two galvanometers are shown at *G*. They record photographically upon the recorder *R*.

Stratosphere Cosmic Ray Measurements.—Much of our attention has been devoted to cosmic ray measurements in the stratosphere; and for this purpose we have made considerable use of cosmic ray telescopes operating on the principle of the simple device I have already demonstrated. In fact, such an apparatus, suitably modified and adapted, was used on the

[4] Since this was written, the investigation has been completed and published. *Phys. Rev.*, **50**, 403 (1936).

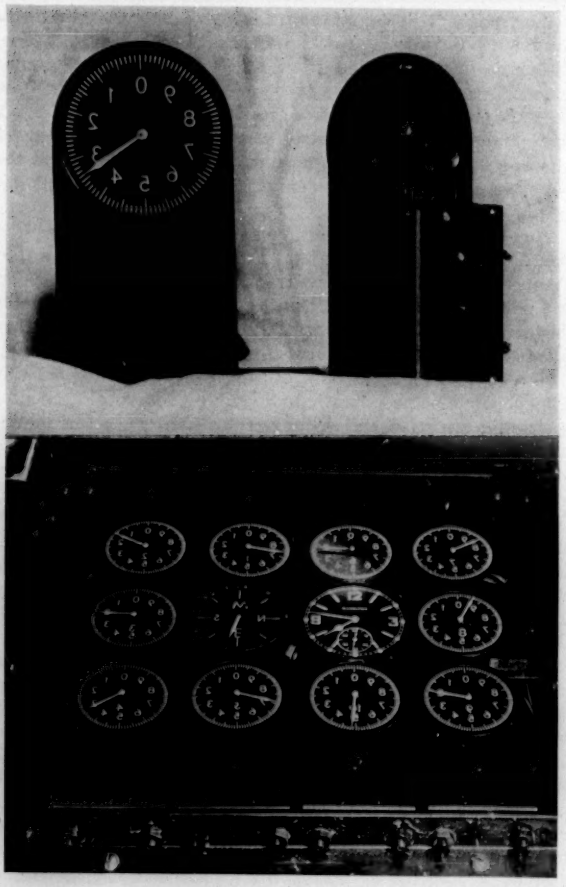
last National Geographic U. S. Army Air Corps Stratosphere flight. I referred to this apparatus last year and pictures of it are contained in the report for last year. It was designed by Dr. G. L. Locher, Dr. W. E. Danforth and myself. It will suffice therefore to pass over these matters rather briefly at this time. Figure 9 shows a central column containing

FIG. 9.



certain electrical equipment. To the right are five boxes containing five telescopes which can be pointed at different angles to the vertical. To the left is another set of five telescopes pointed at corresponding angles. The telescopes at the left differ from those at the right only in the incorporation of an extra feature in the right hand telescope, a feature designed to eliminate certain complicating features referred to in my last year's report. Each of the telescopes is connected to a suitable dial mechanism shown in Fig. 10, there

FIG. 10.



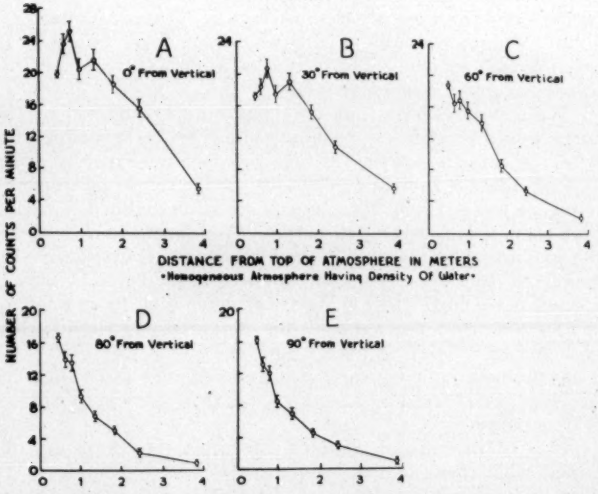
being one dial for each of the telescopes. Every time a telescope records a cosmic ray its corresponding dial moves on by one unit. This box of dials has also a dial associated with compass to record direction and it has a watch to record time. These dials are contained in the box *C*, Fig. 9, and are photographed every half minute by a camera contained in the box *D*. Another method of recording was also used in which every time a cosmic ray passed through a telescope, a shutter was opened in a corresponding light producing device in the box *E*, resulting in a mark being printed upon moving photographic paper.

Let us now turn to the results obtained. Imagine the atmosphere compressed until it attains the density of water. To every point in our actual atmosphere there will correspond one point in this so called homogeneous atmosphere, a point characterized by the fact that the amount of air above that point is the same, whether it is compressed or not compressed. It is convenient to discuss our results as applied to this homogeneous atmosphere. In Fig. 11 we have plotted in a horizontal direction the distance from the top of this homogeneous atmosphere. In the vertical direction we have plotted in the curve marked *A* the number of cosmic rays recorded per minute by our vertically pointed telescope. I may say that since practically all of the observations were taken at the "ceiling," i.e. the highest altitude attained, the data for the highest point are by far the most accurate. The other observations were taken during the descent; and they are less accurate on account of the fewer observations available. They do serve, however, to tell us an interesting story. It will be observed that as we ascend into the atmosphere the cosmic ray intensity first of all increases. However, it does not go on increasing but attains a maximum value, after which it decreases. This result had already been observed just prior to our observations by Regener using unmanned pilot balloons. The few observations which we were able to salvage from the first National Geographic flight which, as you will recall, ended in catastrophe, did not extend to altitudes great enough to reveal the maximum. I may say, however, that while Regener's data gave a 39-fold increase in cosmic ray intensity from sea level to the value at the maximum, our

results show a 51-fold increase. In addition to the maximum at the highest altitude, there will be observed a second maximum at an altitude somewhat lower.

Last year, I cited the details of a theory of cosmic ray action in which I had been interested, and according to which the things observed were for the main part not the primary cosmic rays, but secondary cosmic rays shot out from the atoms of the air by the primaries. The increase of effect of

FIG. 11.



the measured intensity with altitude arose from the idea that the numbers of rays shot out by the primaries in a given distance increased with the energies of the primaries so that in the higher regions of the atmosphere where the primary energy was greater than in the lower regions, more secondary rays were shot out and consequently a greater intensity was measured. From this view we might expect the measured intensity to increase with altitude until we come sufficiently near the top of the atmosphere to result in a curtailment of

the secondaries to be observed as the result of the limited amount of air above the point in question which is to produce them. On such a view, therefore, we would expect a rise to a maximum of the kind found followed by a decrease in the intensity with further increase of altitude. When we submit the matter to calculation it turns out that the distance from the top of the homogeneous atmosphere to the peak should be roughly representative of the distance which the secondaries can travel in the atmosphere. This distance comes out to be 82 centimeters for air compressed to the density of water, and corresponds to an energy of those rays of such an amount that about five hundred million volts would have been necessary to produce that energy. The second maximum corresponds to a somewhat greater secondary energy.

We should expect that the maximum at the top of the curve would become less pronounced as the angle between the telescope and the vertical is increased; because at any given altitude there is more air in the line of the telescope from the telescope to the top of the atmosphere in an inclined direction than there is in a vertical direction. We should in fact expect the maximum to become less pronounced and gradually disappear as the angle from the vertical is increased. This is just what we find. In Fig. 11 *B* corresponding to an angle of 30 degrees from the vertical the maximum is slightly less pronounced. At 60 degrees from the vertical (see Fig. 11 *C*) it has practically disappeared and at 80 degrees and 90 degrees (see Figs. 11 *D* and 11 *E*) from the vertical there is no vestige of it remaining.

It is of interest to compare the most recent results obtained with those of the former National Geographic U. S. Army Air Corps Stratosphere flight and with those of the flight made by Dr. and Mrs. Jean Piccard in the fall of 1934. The quantity whose values we shall compare is the ratio of the intensity of the radiation at a chosen altitude to that at sea level. At the 53,000 feet altitude where observations were made in the Piccard flight, this ratio was 44, while the most recent flight gives 42 for this altitude. At the highest altitude, 40,000 feet, at which observations were made in the former National Geographic flight the ratio is 38, while the most recent flight gives for that altitude 36. The agreement

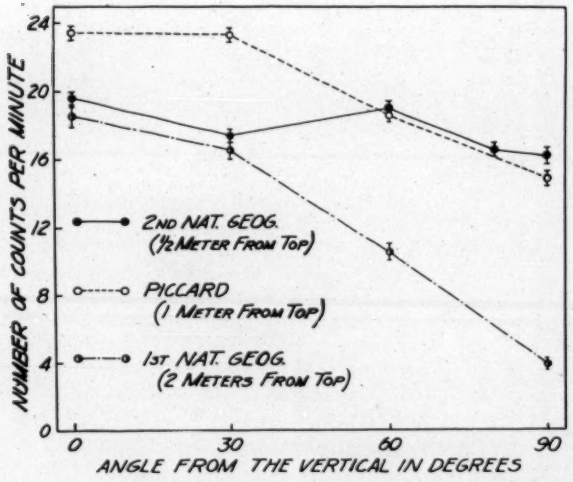
between the present flight and the former flights is thus extraordinarily good, particularly when it is remembered that while all three pieces of apparatus were designed and constructed at the Bartol Foundation, an entirely new apparatus was used on each occasion, and there were some minor changes in design between the equipment for each of these flights.

Another matter of profound interest is the variation of the number of rays received with change of direction of our telescopes from the zenith. At the surface of the earth the number of rays received in the horizontal direction is negligible compared with that received from the vertical. This results from the great thickness of atmosphere which horizontal rays must traverse. Even at 40,000 feet we should expect but a small number of rays from the horizontal as compared with the vertical. We were surprised, therefore, when our results obtained in the first of the flights gave a horizontal intensity as much as 20 per cent. of the vertical at 40,000 feet. Evidently something was happening to eliminate the absorption which the rays might be expected to experience in coming horizontally through the atmosphere. We concluded that the rays which entered our telescopes horizontally had not really traveled all the way through the atmosphere in that direction, but had been swung around in their paths from more vertical directions by the earth's magnetic influence. We were therefore not so surprised when, in the Piccard flight, we found that the horizontal effect was more than 50 per cent. of the vertical effect at 53,000 feet. In the most recent flight, the number of rays received in the horizontal direction at 72,000 feet is practically equal to the number received in the vertical direction. Figure 12 shows the intensity of the cosmic radiation plotted against the angle from the vertical, for the observations obtained at the highest altitude in the three flights.

It is to be observed that with a horizontal telescope the cosmic rays come from both ends; and the intensities above cited refer to the total number of rays counted per unit of time by the telescopes. In spite of the fact of a telescope counting from both ends for the horizontal case, or for any other case, however, its records are truly representative of the contribution of the rays to the ionization which would be

produced in the gas in a closed vessel for the direction concerned. For this reason, it is possible to utilize such curves as are represented in Fig. 12 for a computation of the total ionization in a closed vessel at any of the altitudes concerned. If we do this we find that our observations indicate an increase by a factor of 100 between the ionization per second which would be produced in a closed vessel at 57,400 feet, the altitude of the maximum in Fig. 11 *A*, and that produced

FIG. 12.



at sea level. Taking the corresponding case for the Settle-Fordney flight for the same altitude an ionization per cubic centimeter per second 400 times that at sea level was obtained on the basis of a value of 2.48 ions per cc. per second quoted by R. A. Millikan. Our ratio calculated for the change of ionization with altitude is consequently less than that observed by a factor of 2. It is probable that the difference is the result of the contribution of the walls of the vessel in ionization measurements. We know that the cosmic rays

cause the emission of secondary radiations from substances and these radiations contribute to the production of ionization. Our knowledge of this phenomenon leads us to the conclusion that if we should start with a vessel of very small wall thickness and gradually increase the thickness, the ionization within would first increase on account of the presence of these secondary rays but would subsequently diminish as the wall thickness was further increased to a point where it became effective in absorbing the entering rays. It is the ionization from the secondary rays originating in this innermost layer of the vessel with which we are mainly concerned. Now we know that the cosmic radiation consists primarily of two components, a soft component and a hard component, the former of which increases with altitude at a rate of four times as fast as the corresponding rate for its companion, the hard component. At the surface of the earth the soft component contributes only a small portion of the measured intensity, the main part being contributed by the hard component. On the other hand, at great altitudes the soft component dominates the hard component. Now our knowledge of the production of secondary radiations from materials teaches us that the intensity of these secondary radiations increases with altitude at about the same rate as that of the soft component. If, therefore, there is even a little of this secondary radiation at sea level, an amount whose contribution to our ionization measurements is only a fraction of the contribution by the hard component, that small amount will be very significant when it has experienced the large increase which it gains at high altitudes. The net result is that the ratio of the high altitude intensity to the sea level intensity will be much greater than had this secondary radiation been absent. In the case of the counter measurements this secondary radiation is not so effective, for various reasons, not the least of which is the fact that the material of the counter telescope apparatus, being of low atomic weight on the average, is less effective in producing such radiations than is the material of which most ionization chambers are made. By submitting the matter to calculation in terms of our knowledge of the magnitudes of the quantities concerned it becomes readily possible to account, along the foregoing lines, for the difference between the ioniza-

tion chamber measurements and those obtained from our counter telescopes.[5]

If for the various angles from the vertical, we should plot the intensity of the cosmic rays as measured by our telescopes against the path traveled as measured, in our equivalent water atmosphere from the top of the atmosphere along the direction of the axis of the telescope, we should expect to obtain a curve which was the same for all angles, at any rate to a first approximation; for, obviously, if the rays enter the atmosphere equally in all directions, the only thing which our telescope should be aware of is the distance from itself to the top of the atmosphere measured along the direction of its axis; since it is this distance which determines the absorption of the rays. When for the different angles we plot the curves against this distance, we find, as shown by Fig. 13 that except near the top of the atmosphere, and except for the largest zenith angle all of the curves fall more or less together. As already stated, the situation is complicated by the influence in bending the paths of the cosmic rays, so that we should expect abnormalities to exhibit themselves at the highest altitude and at large zenith angle.

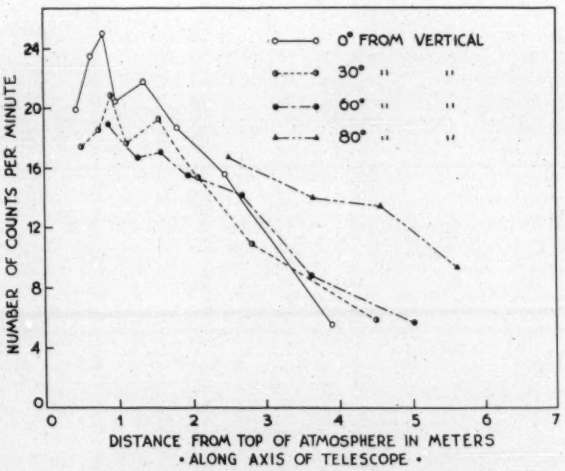
Incidentally it may be mentioned that it has been customary in the past to reduce observations taken with ionization chambers to corresponding data for vertical radiation such as is measured by our counters, by a process in which it is assumed that the variation of intensity with zenith angle is of the same form as is found at sea level. Our intensity zenith angle curves for the flight of Explorer II, those for the Piccard flight, and those for the flight of Explorer I show that this procedure is entirely inapplicable for high altitudes.

It is unfortunate that we were unable to obtain more observation for altitudes other than the highest altitudes; but, that circumstance was unavoidable and was determined by the processes concerned with the navigation of the flight itself.

[5] In the comparison of the observations from different flights, however, and this applies also to our comparison with Regener's data, we cannot speak with certainty as to what the comparison should yield without knowledge of the effect of differences in the latitudes at which the experiments were performed. Unfortunately, our knowledge of what the latitude effect should be at high altitudes is very meagre.

Arrangement has been made with the Army for a series of airplane flights at the lower altitudes; and, we are planning to send the apparatus up again in this way so as to improve the accuracy in those regions where the balloon flight itself was not able to supply us with data as good as we could have wished. As I stated in my report last year, in my judgment one of the most important things to determine is an accurate knowledge of the variation of the cosmic ray intensity in one

FIG. 13.



definite direction, preferably the vertical direction in the atmosphere, because the story of that variation is controlled directly by and is therefore a means of obtaining information concerning the fundamental processes which are at work in giving rise to the phenomena which we actually observe in our measurements of cosmic radiation.

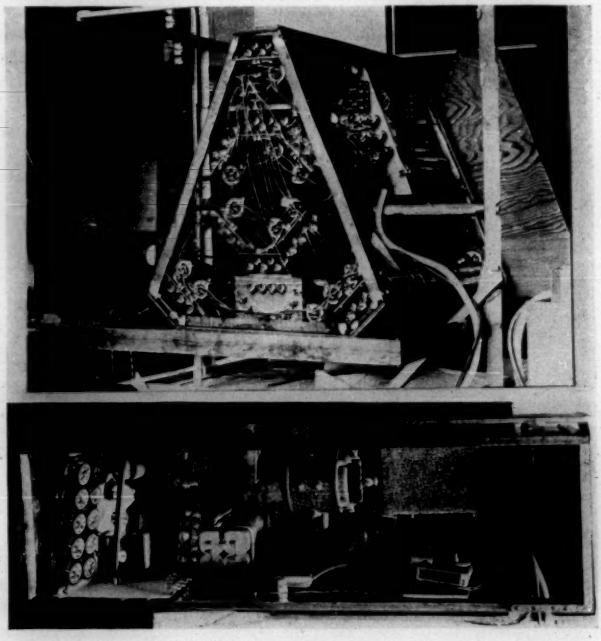
A variation in the method of attack upon the problem is being made by Dr. T. H. Johnson and Professor Jean Piccard, who is now associated with our laboratory. Following the

general principle of the method used by Regener, Drs. Johnson and Piccard are sending relatively small unmanned balloons to different altitudes for the purpose of measuring the intensity of the cosmic radiation with Geiger counters. One new element involved in this procedure consists in the utilization of a balloon made of cellophane instead of rubber as has formerly been used. Cellophane is very light and strong and is therefore well adapted to the purpose. The cosmic ray recording mechanism comprises in the first place a Geiger counter telescope unit. Some of the parts normally associated with such a unit would be inconveniently heavy to carry on a balloon of this type. In particular, the high potential battery is such a part, as is also the recording mechanism. For this reason Dr. Johnson is using what amounts to practically a little electrostatic machine which generates the potential, and is operated by the weight of the whole apparatus hanging from the balloon. This weight falls slightly in relation to the balloon during the flight and operates the mechanism in the same kind of way that the weights on a grandfather clock, by falling, operate the clock. Then instead of having a recording mechanism on the balloon, the impulses through the cosmic ray telescope are caused to operate a small radio transmitting device by which means it is possible to observe the impulses by a receiving apparatus on the ground. Finally, it is necessary to know the pressure of the external air in order that the altitude may be known. This is again given by radio transmission from a device in which a column of mercury is caused to make contact with a wire, complete an electric circuit and send out a radio impulse which can be received on earth. Unmanned balloons of this type have the advantage that they can be sent up at all latitudes and from places where the ascent of a large balloon would be impracticable. Moreover, the cost of such an apparatus is negligible compared with that of a normal stratosphere flight. One cannot expect to attain the same degree of precision in any one experiment as can be obtained in a larger balloon; but one may repeat the measurement several times. The whole apparatus is nearing its final stage of completion and it is hoped that the initial flight may be planned in the near future.

Measurement on Variation of Cosmic Ray Intensity with

Latitude.—In my former reports I have said much concerning the effect of the earth's magnetism in deviating the paths of cosmic rays which approach the earth. Such deviations result in variation of cosmic ray intensity with latitude. Indeed, it

FIG. 14.



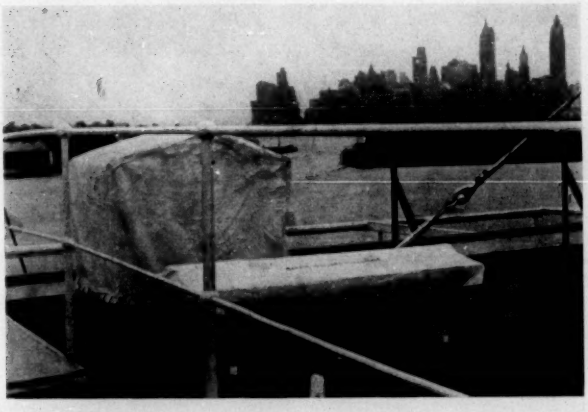
The upper picture shows a system of cosmic ray counters arranged to measure the intensities at different zenith angles.
The lower picture shows the recording apparatus, with the recording dials to the left.

was by the discovery of this latitude effect, by J. Clay in Europe and by A. H. Compton in a world survey that we were gradually forced to the conclusion first that some and then practically all of the primary cosmic rays entering our at-

mosphere are of the charged particle type. Associated with this latitude variational phenomenon was another having to do with the variation of cosmic ray intensity from different points of the compass; and, as you will recall, Dr. Johnson of our laboratory has been very active in investigating this phenomenon with Geiger counter telescopes in different parts of the earth and at various altitudes.

The actual variation of cosmic ray intensity with latitude has usually been made by measuring the ionization which the rays produced in a gas contained in a spherical chamber. By

FIG. 15.

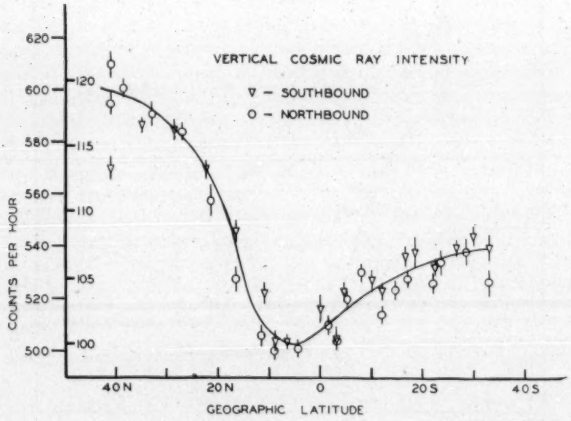


such a procedure one studies a sort of average of the intensities from different directions. A more clear-cut result is obtained if one should study the latitude effect corresponding to the intensities in specific directions. With this end in view Dr. Johnson devised a Geiger counter telescopic arrangement suitable for mounting aboard a ship and operated almost exclusively automatically. The apparatus was also capable of determining for different directions the difference between the intensities from the east and from the west. The records of the cosmic ray counters were made by causing them to operate

a system of dials which were photographed automatically at intervals.

Figure 14 is a picture of the apparatus and is sufficiently described by the legend attached. Figure 15 is a photograph of the enclosed apparatus mounted aboard the ship. Through the courtesy of the Grace Line this apparatus was taken on two occasions from New York to Valparaiso, Chile and back. The most successful observations were obtained on the second trip and are represented in Fig. 16 where the latitude is indi-

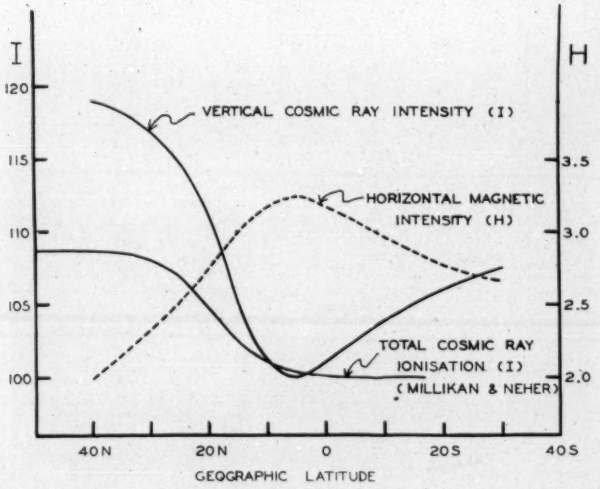
FIG. 16.



cated horizontally and the vertical intensity vertically. The very distinct dip in this curve is representative of the latitude effect which is here more pronounced than is given by ionization chamber measurements since the vertical intensity is more sensitive to the latitude effect than is the average intensity. One of the most interesting features of this curve lies in the position of the minimum which coincides with neither the geographical equator nor the magnetic equator. The most simplified view of the latitude phenomena would give this minimum as occurring at the magnetic equator, which is 15 degrees south of its place of actual occurrence. When Dr.

Johnson examined the distribution of magnetic intensity in these regions, however, he found, as is quite customary in terrestrial magnetism, a relatively large local variation. It is believed that this local variation extending outwards, of course, far beyond the limits of the earth's atmosphere is responsible for the shift of the minimum from the average magnetic equator. It is found that this idea fits the facts quantitatively, as will be seen from Fig. 17, in which now the

FIG. 17.



vertical intensity is plotted against latitude as before but is accompanied by a plot of the horizontal magnetic intensity. It will be seen that the actual horizontal magnetic intensity has a maximum where the vertical cosmic ray intensity has a minimum. The situation is in fact as though the magnetic equator were distorted in this region to the extent of the 15 degrees already referred to.

As already stated, the observations also extend our knowledge of the east-west asymmetry. As regards the gross figures

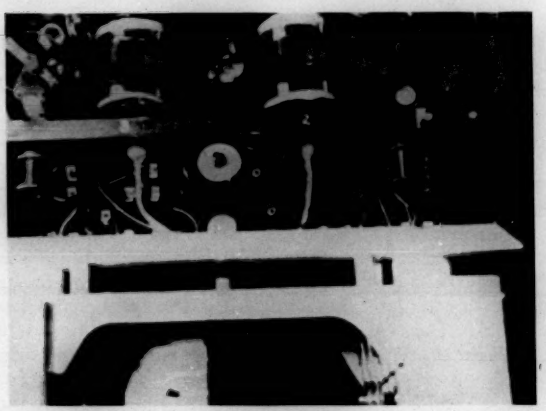
the results are here in harmony with what was to be expected. A detail of special interest, however, lies in the fact, again to be expected from theory, that the latitude effect of the cosmic ray intensity varies with the zenith angle and with the azimuth of the telescope. Although such phenomena can be predicted from theory, their experimental realization is of profound importance because it is by comparing our experiments with the theories at all stages of progress that each supplements and suggests advances continually in the other.

Measurement of Atomic Bursts in the Stratosphere, and Allied Phenomena.—In my former reports I have referred to the fact that cosmic rays falling upon matter, and in particular upon heavy elements, produce, occasionally, sprays of rays which themselves possess the power to do the same kind of things that the cosmic rays do. We speak of these phenomena as atomic bursts, because the whole phenomenon has something of the characteristic of an explosion in which a lot of debris of all kinds is shot out in all sorts of directions. In my last report I pointed out how Dr. and Mrs. Montgomery of our laboratory had found that the frequencies of occurrence of these bursts increased from sea level to the top of Pike's Peak by a factor of 25, whereas the cosmic ray intensity itself increased by a factor of only 5. It was therefore of profound interest to continue these investigations to the still higher altitudes of the stratosphere; and to that end an apparatus was carried on the last National Geographic U. S. Army Air Corps Stratosphere flight. I described this apparatus in my last report, and Fig. 9 shows a picture of it. Atomic bursts occurring in a slab of lead separating S and G send their rays into the sphere S containing compressed nitrogen and in this sphere they produced a spurt of electrical conductivity which results in a surge of electric current as a result of the batteries connected with the sphere. This surge of current was made to operate two delicate electroscopes whose indications were then photographed on a moving film. Figure 18 is a picture of the electroscope assembly. Since the sizes of these atomic bursts vary enormously in magnitude from very small bursts to very large ones, we had to decide which ones we would investigate, since it is impracticable to arrange an apparatus for investigating all sizes and yet having con-

venient simplicity for operation under the conditions of the flight. In view of the fact that former observations had intimated the possibility of very large atomic bursts occurring in the stratosphere, we designed the apparatus with a special view toward the detection of such bursts if they occurred.

If we should assume that atomic bursts phenomena increased with altitude in the same kind of way as the cosmic ray intensities increase, but with a greater rapidity of increase such as would correspond to the observations at sea level and

FIG. 18.



The two electroscopes are shown at the back of the picture. The lamp between them illuminates the fibers and to the right and left of the electroscopes are seen the prismatic optical systems which project the images of the fibers on to the cameras which are shown, partially, in the foreground.

Pike's Peak, then a conservative estimate shows that we should conclude that at the ceiling of the last flight (72,000 feet), we should have observed about 52 bursts above the measurable size, during the period of observation. In actuality no bursts above the measurable size were observed with certainty. We can therefore conclude that the rate of increase with altitude of the numbers of these large bursts does not continue to show itself for high altitudes in the same degree as would be suggested by the rate of increase of bursts of slightly smaller sizes from sea level to Pike's Peak.

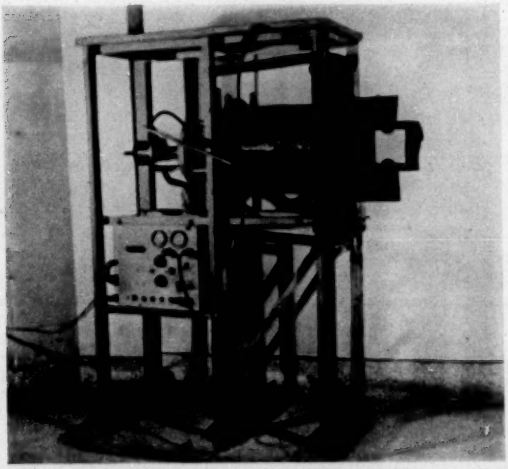
One of the things which it is most of interest to investigate concerning cosmic ray phenomena in the stratosphere is the type of particles which we find there as responsible for the cosmic ray effects. It has been suggested that alpha particles, which are positively charged atoms of helium, are among the things which figure as cosmic rays. It has been suggested that protons, which are positively charged atoms of hydrogen, occur. Positive and negative electrons have also been suggested. For these reasons it would have been very desirable to have carried into the stratosphere an apparatus for observing these particles by the so-called cloud expansion method which has been used so intensively by physicists for the last twenty years. As you will recall, the principle of this method utilizes the fact that if we have a chamber containing moist air and then expand it, the air will cool and condense on any particle which may be found in the vicinity. It will condense upon dust particles, for example. If, however, the air is free from dust, then it will have difficulty in condensing at all. If, however, a ray capable of producing ions, that is, broken molecules, is passed through the chamber at the instant of the expansion, the ions which it produces act as centers of condensation for the water, so that the track of the particle is rendered visible. Dr. Locher of our laboratory has given much attention to the design of such cloud expansion chambers, particularly for the purpose of recording cosmic ray phenomena; and he was one of the first to observe cosmic rays by this method. Figure 19 is one of the cloud chambers of Dr. Locher's design and was indeed made primarily for high altitude work although it is not suitable for work in a balloon.[6]

Dr. Locher designed a special type of cloud expansion chamber for the National Geographic Stratosphere flight. This was all ready for operation and was in the gondola prepared to ascend at the instant when, in the first flight, the balloon ripped on the ground. The necessity of making as sure as was humanly possible of success in the last flight resulted in the elimination of some of the scientific apparatus, particularly that which would require some attention by the

[6] These pieces of apparatus have been described in detail in a paper by Dr. G. L. Locher in *Rev. Sci. Instr.*, December, 1936.

flight personnel and the cloud expansion apparatus had to be eliminated for this reason, so it was not carried on the flight which was successful. However, there is another method of obtaining information somewhat similar to that given by the cloud expansion chamber, although the interpretation of results from it is more difficult. I refer to the use of special photographic plates. Such a particle as an alpha particle when striking a photographic plate dives into the emulsion

FIG. 19.



and reduces the silver salts to a condition which, on development, results in the formation of metallic particles of silver which show as a number of black dots along the track of the alpha particle. The number of these dots per unit of length is intimately related to the ionization which would be produced in a gas per unit of path by the alpha particle. The tracks in the emulsion are, of course, very short; but, by examining them under a microscope it is possible to study them. The tracks produced by hydrogen particles, and by

protons, are quite different from those produced by alpha particles, and by careful observation can be distinguished from them.

Drs. Locher and Rumbaugh have prepared a number of suitable photographic plates and have exposed some of them at the top of Pike's Peak, some of them in the stratosphere and some at sea level. The individual plates were covered with layers of a number of elements so that evidence might be obtained concerning nuclear particles having their origin in these elements. Some of the plates were covered with paraffin.

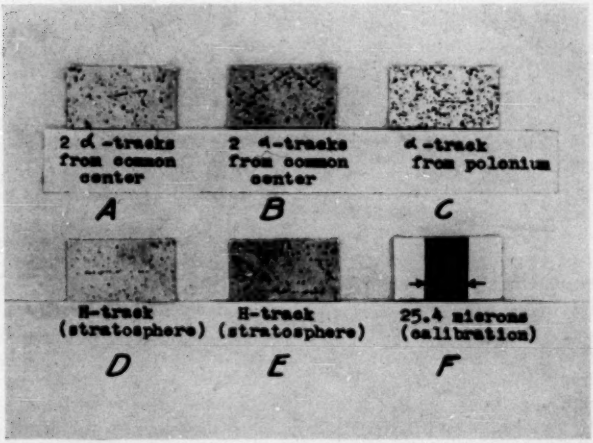
The total plate area exposed in the stratosphere was about 3,000 square centimeters. As you will readily see, a complete examination of all of these plates will take a very long time. It would greatly facilitate matters if everybody in this room took a part, which would probably constitute a greater work for science than listening to my lecture. In all, Dr. Rumbaugh has examined about 70 square centimeters of plate area. Of this 70 square centimeters, 60 corresponds to plates in the stratosphere, and about 10 to paraffin covered plates at sea level or at the top of Pike's Peak.

In interpreting the results from such plates we have first to remember that the atmosphere in its natural condition is contaminated with radioactive material, as is everything else, including the plates themselves. For this reason, alpha particle tracks due to such contamination are always to be found in the plates. Figure 20 is an actual photograph of nuclear particle tracks. Picture *A* and picture *B* show two pairs of alpha particle tracks. While these were obtained in the stratosphere plates they probably correspond to radioactive contamination, particularly as each picture represents two tracks springing from a common center. Picture *C* is an alpha ray track created in the laboratory by exposing the plate to polonium. Pictures *D* and *E* will be referred to later. We may distinguish alpha particles arising from radioactive substances from those which could function as cosmic rays by the fact that the former have comparatively small energy and produce tracks which are very short. Thus, for example, an alpha particle from radioactive material would produce in the plate a track only about 30 or 40 microns in length. An

alpha particle which had an energy such that a hundred million volts would be necessary to produce that energy, and which would correspond to quite a soft cosmic ray, would produce a track about 30 or 40 times as long. However, to safeguard all contingencies a policy has been adopted of comparing the plates exposed at high altidudes with those exposed at sea level.

The search for alpha particles is of importance because it has been suggested that long range alpha particles form an

FIG. 20.



important contribution to the cosmic radiation at high altitudes. Neither in the plates exposed at the top of Pike's Peak nor in the 60 square centimeter of plates exposed in the stratosphere did Dr. Rumbaugh find as much as one alpha ray track which was of sufficient length to have significance as a cosmic ray. However, I think we must be careful as to how we interpret these results in their bearing upon the possible existence of cosmic ray alpha particles. For, as I have already remarked in connection with the experiment

designed to search for protons at sea level, a charged particle of high energy would ionize only to an extent comparable with the ionization produced by a high energy electron. High energy electrons do not effect photographic emulsions, and there is every reason to believe that if the cosmic rays contained alpha particles, the majority of these alpha particles would have energy too high to affect the emulsion. The story in fact becomes exactly analogous to that cited for the proton experiment. Our plates will be insensitive to all of the alpha particles passing through them except those which are so near the end of their journey that their photographic activity is large.

If for the moment we should assume that all of the rays measured by our counters in the stratosphere were alpha particles we should find that, using our Geiger counter data, about 3,000 alpha particles must have passed through each square centimeter of the plates during the two hour period at the ceiling, and through the 60 square centimeters examined about 600,000 alpha particles would have passed. Now according to the data quoted by Professor Compton about 6 ten thousandths of the particles passing through an area would be absorbed in the next millimeter of their journey in a substance of the density of water. Moreover, those particles which have only the equivalent of a millimeter of water path left to them would according to theory have an energy such as would be given to an electron by a hundred million volts. It is believed that such particles would have enough energy to show themselves as visible tracks.[7] We should therefore expect to have found on the 60 square centimeters of plate area exposed for two hours in the stratosphere about 6 ten thousandths of 600,000 tracks in other words about 360 long range alpha particle tracks. It would therefore seem that certainly less than something of the order of 1 per cent. of the cosmic rays measured by Geiger counters in the stratosphere can be attributed to high energy alpha particles.[8]

[7] As a matter of fact, Dr. Wilkins, who also had some plates exposed in the stratosphere, has reported the existence of one track corresponding to an alpha particle of a hundred million electron volts energy.

[8] Since this report was presented, the complete account of this work has been published, see L. H. Rumbaugh and G. L. Locher, *Phys. Rev.*, **49**, 855 (1936).

The significance of these results will naturally be enhanced as more of the plates are examined.

Another matter of significant interest concerns the search for neutrons. As I have already remarked, neutrons are difficult to detect directly. They do not ionize a gas through which they pass and presumably they do not affect photographic plates. However, they are very efficient in imparting high velocity to hydrogen atoms which they encounter, knocking out of them their simple nuclei which are protons, and endowing them with sufficient energy to make them observable by ionization effects, by cloud chamber phenomena, or by photographic action. Almost any substance containing hydrogen will serve as a target in which the neutrons may generate protons. Paraffin is such a target, and even the emulsion of the photographic plate itself serves as a target. Now at sea level Dr. Rumbaugh has found less than one track per two square centimeters during a period of two months. In fact in the whole six square centimeters of plates exposed and examined at sea level, only two tracks which might have been proton tracks were observed for the period of two months. However, on the other hand about six square centimeters of the paraffin covered plates exposed for two hours in the stratosphere yielded about 30 proton tracks. Figure 20, *D* and *E*, shows two such tracks. A careful examination of them shows that the grain spacing is about one and a half times as great as for the alpha particle tracks shown in *A*, *B* and *C*. It would therefore seem reasonable to suppose that neutrons exist in measurable amounts in the stratosphere. This does not necessarily mean that they contribute an important factor in cosmic ray phenomena. They do not affect our counters directly. They could not affect them through the protons which they bring into evidence because those protons have too short a range to pass through our counter telescopes. We can arrive at the energy of the neutrons by dynamical considerations applied in relation to the energy which they impart to the protons. And taking into account their efficiency of production of protons and therefore the number which actually exist in relation to the number which Drs. Locher and Rumbaugh have found we arrive at the conclusion that their total energy

is insufficient to contribute a significant amount to the total ionization of the atmosphere in the stratosphere.

The Pike's Peak data on these plates have an interesting bearing, from another angle, upon the possibility of protons forming part of the cosmic radiation. Suppose, for example, that all of the radiation at sea level was of the proton type. Then the number of protons passing through a square centimeter in an hour at sea level would be about 36. Even though we should assume that no more protons than are to be found at sea level are to be found at the top of Pike's Peak, we should then expect that through the plate area 6 square centimeters there exposed, about 216×800 protons would pass during the 800 hours in which the plates were exposed. Now we know that a ten million volt proton would affect a photographic plate and that such a proton has a range of about one millimeter of water. If we assume the coefficient of absorption of the protons cited by Compton, namely 0.08 per meter of water, we arrive at the conclusion that 0.08/1000, i.e., 8×10^{-5}, is the fraction of the protons passing through a plate which would record themselves. This fraction when applied to the number 216×800 given above results in 8 protons as the number which should have given tracks in the Pike's Peak experiment. In actuality not more than two, and these both doubtful, were observed. We therefore have from this entirely different angle evidence against the occurrence of protons as a significant contribution to the primary cosmic radiation. As a matter of fact, the fact that the observations were taken at the top of Pike's Peak has no particular bearing upon this discussion. It simply happens that we had a period of 800 hours exposure for the Pike's Peak plates in contrast to a much smaller number of hours for the sea level plates.

Further Experiments on the Nature of Cosmic Rays.—In my last year's report I described a theory of cosmic rays, which has since been published, and which was to the effect that the primary rays, whatever they are, pass for the most part right through the atmosphere. It was supposed that they shoot out from the atoms of the air secondary rays all along their path and that it is these rays which are for the most part measured by our Geiger counters. The increase

of the measured intensity with altitude is provided for by the assumption that the number of long range secondaries produced per unit of path of the primaries increases with altitude approximately in proportion to the energy of the primary particle, which primary energy increases of course with altitude because the primaries lose energy by the production of secondaries as they descend into the atmosphere.

Now it would, of course, be highly desirable to make a direct experimental test of this hypothesis. Viewed in its simple aspect the situation is as follows. Suppose that a primary ray AB produced secondaries and that the range of these secondaries is a certain distance R. Then if the hypothesis is correct and if we should place at A an area of Geiger counters so arranged that they record separately singles, doubles, triples, etc., we might expect that their actual records would always be of practically simultaneous rays as many in number as were produced in the distance R. In practice we should not expect to realize this condition, however, because the distance R in air might be several hundred meters and the spreading of the secondaries would prevent their striking an area at A which was of laboratory dimension. However, it is possible to work around this difficulty by the following procedure. Suppose we first measure the rays received by our counter area from the sky. We may expect that nearly all of these rays will be unaccompanied by partners. Let us now place over the counter area a layer of water of thickness greater than the range R of the secondaries. The primaries will produce secondaries which are more closely spaced under water than in the air, so that the spreading will not be as important. If, as seems not unreasonable, the range R of secondaries is of the order 3 meters in water, all of the secondaries, or a goodly proportion of them, produced by a primary directed through the center of the area might themselves pass through the area. Under these conditions all of the rays passing through A would be accompanied by partners. It is thus possible by such a procedure to test the hypothesis as to practically every measured cosmic ray being accompanied by partners produced, presumably, by a common agent. In general it would be impracticable to deal with a thickness of water as great as

the range R, and it becomes necessary to study the meaning of the experiment when applied to a smaller thickness h. Under these conditions there will be a proportion of the secondaries received by A which have come through the water from distant points in the atmosphere, and the partners of these rays will, in general, fall well outside of the area. Let s be the average distance between the ejection of successive secondaries from the water by a primary. Then it is possible to calculate the fraction of primary rays which will be accompanied by no secondaries from the thickness h, by one secondary from the thickness h, by two secondaries, and so on. Students of probability will recall that if x is the average number of secondaries ejected by a primary from the thickness h, the chance of ejection of n secondaries from that thickness is $x^n e^{-x}/n!$. The value of x in our case is h/s, from which we can readily show that if we have N primaries, and if h/s is reasonably small, we may expect $N(1 - (h/s))$ rays to be unaccompanied by secondaries.[9] Hence, Nh/s rays will be accompanied by one or more secondaries.

If the water were not present we should receive practically no secondaries from the primaries which passed through A, but we should receive secondaries which had scattered from other primaries which had not passed through A, and on the whole the *number* of secondary ranges received would be the same as if all of the secondaries from the N primaries had passed through A, but the number of these secondaries per primary would not pass through A simultaneously with one another or with any single primary passing through A. The number of such secondaries from the N primaries will be NR_a/s_a where the subscript refers to air. If, as seems reasonable R_a/s_a is the same as R/s for water, we may write for the number in question NR/s. If h/s is small, this will practically be the number of single secondary rays which pass through A per N primaries, and the corresponding number of single rays primary or secondaries is $N(R/s + 1)$. Hence if p = number of counter discharges containing more than one ray, and P = number of single rays, primary or

[9] Strictly speaking, $Ne^{-h/s}$ are accompanied by no secondaries, $N(h/s)e^{-h/s}$ by one secondary, $N(h/s)^2e^{-h/s}$ by two secondaries, and so on.

secondary

$$\frac{p}{P} = \frac{Nh/s}{N(R/s + 1)} = \frac{h}{R + s}.$$

If $h = 1$ meter, and $R + s$ is as great as 10 meters, p/P would amount to 0.1.

In view of the possibilities that the primaries may not ionize, it is important to extend the calculation to this case. We are now concerned with the case where we have two or more secondaries simultaneously from the thickness h. The number in question is

$$p = N - N\left(1 + \frac{h}{s}\right)e^{-h/s}.$$

Our value of P for the present case is NR/s and

$$\frac{p}{P} = \left(1 - \left(1 + \frac{h}{s}\right)e^{-h/s}\right) \Big/ (R/s);$$

if h/s is small this becomes

$$\frac{p}{P} = \frac{h^2}{2Rs}.$$

For a case where $h = 1$ meter of water, $R = 3$ meters and $s = 10$ meters, for example

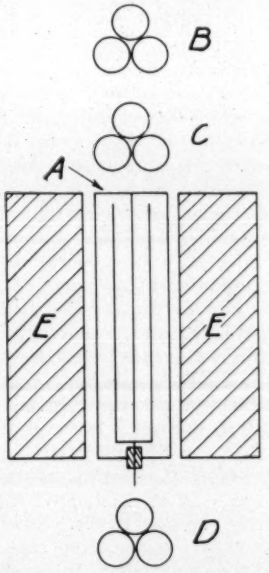
$$\frac{p}{P} = 1/60.$$

In the case of an area of 500 square centimeters, P would amount to five counter discharges per second, and p would amount to 1 counter discharge of multiple variety in 12 seconds. Mr. Ramsey and I are now engaged upon an experiment founded upon the foregoing principles. I may add that certain additional precautions must be taken to eliminate the effects of small atomic bursts or showers originally in the water, but I will not pause to describe these here.

The Ionization Produced per Centimeter of Path by Cosmic Rays.—I have already stated that a charged particle of high energy carrying the electronic charge produces about 30 ions per centimeter of path. It is not so long since there was considerable doubt as to the magnitude of this quantity,

values ranging as high as four times the above value having been quoted. The former values had always been obtained by indirect methods. Two or three years ago, with the assistance of Mr. Ramsey, I was able to devise and utilize a direct method for the measurement of this quantity with the result that the lower values were confirmed.[10] It was clear

FIG. 21.



from the experiment that certain additional phenomena of interest were playing a part. Moreover, the experiment was not designed to give results of the highest accuracy, but rather to test the gross features of the phenomena. Since that time Mr. Ramsey and I have remodeled the experiment in such a way as to give more accurate results. The general principle of the method is represented in Fig. 21. *A* is a

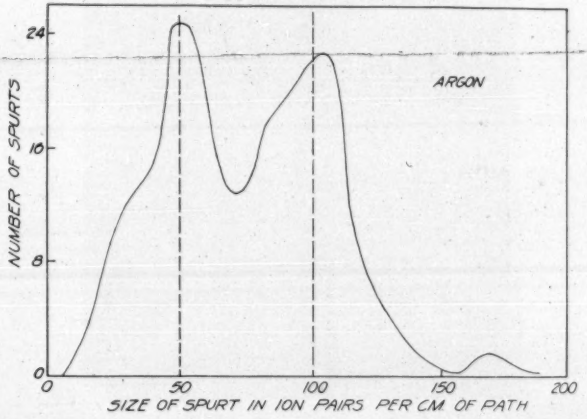
[10] W. F. G. Swann, *Phys Rev.*, **44**, 961 (1936).

copper cylinder 15 centimeters long and 7.5 centimeters in diameter. We wish to measure the spurts of ionization produced by a single cosmic ray traveling nearly parallel to the axis of this cylinder. In order to concentrate our attention exclusively on such rays, therefore, we had three Geiger counter areas *B*, *C* and *D* above and below the cylinder, arranged so as to record only when a ray passed through the uppermost and lowermost areas. The spurts of ionization were measured by the utilization of an amplifier and suitable galvanometer whose design formed one of the important features of the experiment but which we need not describe here. The plan was then to pay attention only to those spurts of ionization which were accompanied by a record from the counters. The collection and electrical measurements of the spurt produced by the ions involves having a central electrode with a difference of potential between itself and the outer cylinder. If this central electrode is very small the time of collection of the ions is large; and during that time of collection, other ions may be generated by rays passing through the large cylinder in all sorts of directions. This bonus to the spurt of ions measured may constitute a very serious error. For this reason the central rod should be large. If, however, it is large, then the most desirable rays for our purpose, namely those which pass very nearly parallel to the axis and through the center of the cylinder, will lose a lot of their ionization path in the rod. For this reason the rod was made hollow, so that ions could be produced inside of it. Then for the collection of these ions a central wire was placed down the hollow rod. It was arranged that the time of a passage of an ion from the wire to the hollow rod was sensibly the same as the time of passage from the outer cylinder to the hollow rod and was as small as possible. It was the hollow rod that collected the ions measured; and, it will be seen that, except for the small path in the very thin wall of this rod itself, the whole path of an ionizing ray was effective in contributing to the measured results.

The main story of the results is contained in Fig. 22, in which the abscissa of any point represents the size of the spurt measured by the number of ions, and the ordinate represents the numbers of spurts obtained in a given time and

corresponding to a small specified range of sizes centering around the size specified by the abscissa. The interesting thing about this curve is that there are two main peaks indicating spurts one of which is double the other. The peak for the spurts of the lower size corresponds to rays which produce about 50 ions per centimeter of path in argon at atmospheric pressure. The story of the other peak is of considerable interest. The fact that the spurts for this peak are just double those for the other suggests that two rays are involved in the larger spurts, for by none of the recognized

FIG. 22.



theories of ionization would we expect to find two different entities, two entities differing in charge for example, of such a nature as to have ionization efficiencies in the ratio 2 to 1. It is probable that the double values are produced by two electron-like rays passing through the vessel together. The simultaneity of these rays demanded by the fact that they contribute their quota within the same small time of collection prohibits their being regarded as the result of two unrelated rays which happen to go through the vessel together. The most obvious possibility lies in the supposition that a single

ray passing through the top of the cylinder may produce therein a secondary ray within a distance of emergence from the wall, on the inside, less than the range of the secondary ray. In this case the secondary will pass through the gas and contribute to the ionization.

The general background which prevents the peaks from being sharp and provides for spurts of sizes different from those of the peaks, has an interpretation which is bound up with certain complications which we shall not consider now,

FIG. 23.

but which do not affect the conclusions as to the specified ionization measured. One of these complications concerns secondaries generated in the gas itself.

The Nature of the Entities Producing Atomic Bursts.—I have already referred to the existence of atomic bursts associated with cosmic ray phenomena. These range over all sizes from bursts consisting of only two rays to those consisting of several thousand. It has been a matter of great interest to students of the subject to inquire whether these bursts are produced by protons or by charged particles or by both. Evidence concerning this matter is to be found

from cloud chamber photographs. Figure 23, for example, shows such a photograph obtained by Dr. J. C. Street, formerly of our laboratory and now at Harvard. It shows a burst originating in a slab of lead, and it is obviously associated with, and presumably produced by an ionizing ray, an electron or positron entering the lead on the upper side. On the other hand, Fig. 24, also obtained by Dr. Street, shows a burst apparently produced by nothing, for there is no ray, which is visible by its effects, entering on the upper side of the

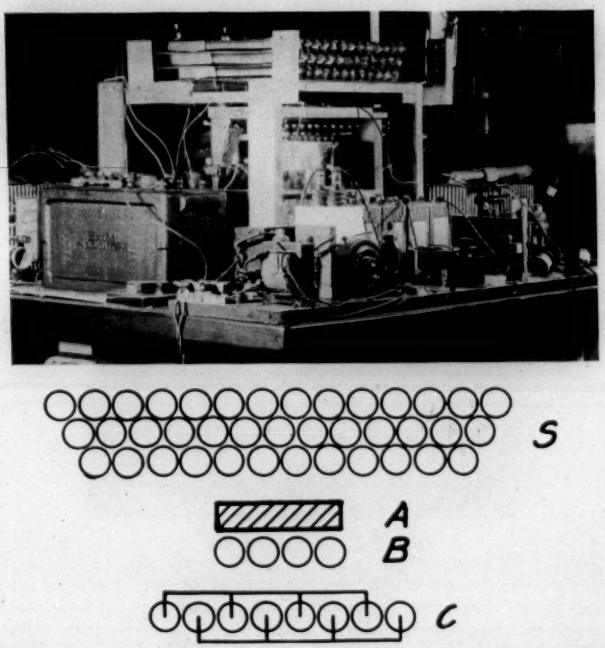
FIG. 24.

lead. This phenomenon could have been produced by a photon ray because photons do not ionize and therefore do not record themselves in the cloud chamber. The cloud chamber therefore provides a means of ascertaining what fraction of the bursts are produced by ionizing and what fraction by non-ionizing rays. In order not to be pedantic I shall say that it provides a means of determining what fraction of the bursts are produced by electrons and what fraction by photons. However, the cloud chamber method has its disadvantages as well as its advantages, and, in order

to attack this problem by an entirely different procedure, Mr. W. E. Ramsey has devised and put into operation an experiment which may briefly be described as follows.

In Fig. 25, A is a slab of lead in which the bursts are produced. Above A is an area of Geiger counters labeled S.

FIG. 25.



Below A were two other counter areas B and C. The geometrical arrangement of S is such that no ray can go through the areas A and C without going through S. The purpose of S is to indicate every time an ionizing ray goes through it. It is first necessary to ascertain how well it knows this. To

that end it is first dispensed with and *B* and *C* are arranged so that they will record only when a ray goes through both. Let us suppose that a hundred rays are recorded by *B* and *C* in fifteen minutes with *S* not operating. The second experiment then is to arrange the electrical circuits so that if *S*, *B*, and *C* all operate no record will be made. In other words, the circuits are arranged so that the record made by *B* and *C* is killed as the ray goes through *S*. If *S* is aware of every ray that goes through it we shall under these conditions, with *S*, *B*, and *C* operating, obtain no records at all. If in our period of fifteen minutes where, with *B* and *C* alone operating, we obtain a hundred counts and if with *S*, *B*, and *C* operating we obtain only two, we shall know that *S* is 98 per cent. efficient as a trap and this is what was found. We now insert the lead *A* and the electrical connections to the various counters in *C* are made such that *C* will only operate if more than one of its counters receives a ray. The whole situation at this stage is now this: If an ionizing ray goes through *S*, *B*, and *C* it will do nothing for two reasons. In the first place being a single ray it will not operate *C*, and if it did, *S* would cut out the effect. Suppose an ionizing ray goes through *S* and produces a spray in the lead. Now *B* and *C* will operate but *S* will cut out the effect. Suppose now a photon goes through *S* and produces a spray in the lead, then *B* and *C* will operate, but *S* will not cut out the effect. The records obtained under these conditions tell us, therefore, the number of sprays produced by the photons. Let us now eliminate *S* completely; then *B* and *C* record the number of sprays produced by photons and electrons so that we are in a position to obtain the numbers of sprays produced in a given time by photons and electrons separately.

The results obtained by Mr. Ramsey, which results are at present in the stage of development, are such as to indicate that about two-thirds of the sprays are caused by photons and one-third by ionizing particles, for example, electrons.

As an extension of this experiment Mr. Ramsey is planning not only to seek an answer to the problem for sprays of all sizes considered as a group, but to seek the answer separately for sprays consisting of two rays, three rays, and any number of rays.

Mr. Ramsey has set up for this lecture an apparatus to demonstrate the actual existance of these sprays from lead.[11]

Further Experiments Upon Ionization per Centimeter of Path.—The problem of determining the number of ions produced per centimeter of path of a cosmic ray is being attacked from another angle by Dr. W. E. Danforth and Mr. W. E. Ramsey. The principle depends upon the mechanism of action of the Geiger counter. You will recall that this appliance consists of a metal tube with a central wire down the middle, the whole being enclosed in a glass tube filled with gas at a pressure of about 8 centimeters of mercury. The potential difference applied between the tube and the wire is just insufficient to cause an electric discharge. If a cosmic ray passes through and produces even one ion, the electric field uses that ion as a sort of bull in a china shop, hurls it against the molecules of the gas, breaking them up into ions which carry on the work of destruction on their own account, so that, finally, the whole insulation of the gas breaks down and there is an electric discharge. If a cosmic ray produces 30 ions per centimeter of path at atmospheric pressure, then at the pressure of about 8 centimeters of mercury it will produce about 3 ions per centimeter of path, and since the Geiger counter tubes are more than a centimeter in diameter there is a considerable approximation to certainty that every ray which goes through will discharge the counter. Suppose now we lower the pressure in the counter. Then, when a stage is reached such that the chance of the cosmic ray producing a single ion in the gas is appreciably different from unity, the counter will cease to respond as frequently as it did before to the cosmic rays passing through it. By an investigation of its lack of counting efficiency with reduction of the pressure of the gas it is possible to arrive at an estimate of the number of ions which would be produced by the cosmic rays per centimeter of path at a standard pressure.

The apparatus used is indicated diagrammatically in Fig.

[11] One of the counter areas used in the first experiment was used again. It was placed horizontally, and the electrical currents were adjusted so that two or more counters had to discharge to give a record. Under these conditions, with lead over the areas, a record was obtained about once per second. Without the lead the records were decidedly less frequent.

26, in which in the first instance we shall confine our attention to diagram *A*. The tube *a* represents the counter under test. *b* and *c* are two other counters and the circuits are such that a discharge will be recorded only when *a*, *b*, and *c* operate simultaneously. In this way we confine our attention to cosmic rays coming within the limits defined by *b* and *c*. In actuality *a* was represented by two counters, exactly similar in type and pressure, placed in tandem to increase the effect. For purposes of description, however, we may neglect this consideration.

FIG. 26.

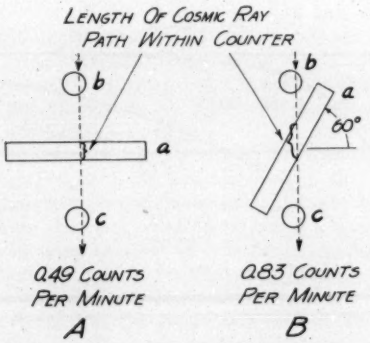
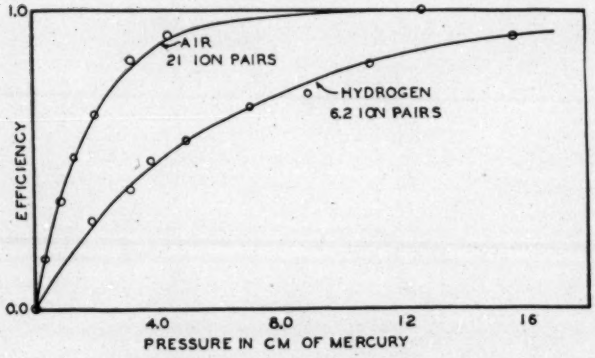


Figure 27 represents the results for hydrogen-filled counters and for air-filled counters. The efficiency of the counter is represented as a function of the pressure. Strictly speaking, the efficiency at any one pressure is sufficient to determine the number of pairs of ions produced per centimeter of path at normal pressure, and, from theoretical considerations, it is possible to draw a curve showing how the efficiency should vary with the pressure for the number of ions per centimeter of path as so determined. In Fig. 27 the curves represent efficiencies as functions of pressure for the ionizations per centimeter of path recorded on them. The curves are calculated theoretically but the points are experimentally determined. The agreement therefore between the points and

the curve is strong evidence of the validity of the arguments upon which the theory of experiment is based.

It is noteworthy that the numbers of ion pairs obtained by this method is smaller than that obtained by Mr. Ramsey and myself by an entirely different method. It must be observed, however, that the method now being described really counts the number of acts of liberation of an electron from an atom by the cosmic rays per centimeter of path. Some of these liberated electrons have energy enough to produce ions on their own account, and, by comparison of these results with those of Mr. Ramsey and myself, we may

FIG. 27.



conclude that about half of the actual ionization observed occurs through the agency of these secondary processes. The method of using a Geiger counter for studying ionization per centimeter of path might possibly be subjected to criticism based upon the idea that the pressure changes may have something to do with the initiation of the disruptive discharge, in the sense that they are a determining factor in that occurrence, quite apart from the effects concerned with the production of the ions by the cosmic rays. We can eliminate this criticism if it can be shown that the effect of change of pressure on the efficiency is related to change of path length

without change of pressure in a manner which would be calculated neglecting the considerations involved in a possible dependence of disruptive discharge on the pressure itself. Now the path length may be altered without altering the pressure by turning the counter under test through an angle of say 60 degrees as shown in Fig. 26*B*, and repeating the measurements. In practice it was found that at a pressure of one centimeter of mercury, an average of 0.49 impulse per minute was obtained for condition *A* and 0.83 for condition *B*. The ratio of these two is 1.69. The path lengths are in the ratio of 2 to 1. Now it was found that, starting with the horizontal counter at the pressure used in this experiment, and then doubling the pressure leaving the counter horizontal, the efficiency was increased in the same ratio, 1.69 to unity. Thus, the increase of pressure has no observable effect on efficiency other than can be represented by proportional increase in path length.

Use of Geiger Counters to Determine the Number of Protons in Cosmic Rays.—I have already referred to our experiments on the search for protons in the cosmic rays. It has occurred to Mr. Ramsey that the principle of using a Geiger counter at low pressure may be used to give an independent answer to the question. It will be recalled that the first experiment which I have already described makes use of the fact that as we get near the end of the range of a proton, the ionization per centimeter of path drops considerably, so that there is quite a large range of path of a proton in which the ionization is far above the normal. Now if the primary cosmic rays are protons, then those particular protons which pass through one of our counters so near the end of their range that they produce especially high ionization will not be so affected by the pressure reduction in the counter as would be the case if they were electrons. It will be seen that the story of diminution of efficiency of the counters with pressure is intimately bound up with the question of whether some of the rays which operate it are protons or whether they are all of the electron type. Mr. Ramsey and Dr. Danforth are engaged upon the problem of seeking an answer to the question as to the possible number of protons which may be admitted as claimants for the position of cosmic rays by an examination

of the dependence of efficiency of Geiger counters upon the pressure of the gas within them.

Further Experiments on Cosmic Ray Bursts.—Last year I described certain investigations which had been carried out by Dr. and Mrs. Montgomery on the subject of atomic bursts. These investigations have been continued, and have led to certain important conclusions, some of which are, however, of a nature too complicated to permit of presentation in a report of this kind. The results have already been published in three papers which have appeared during the last year. In one of these papers the Montgomerys have derived the mathematical expression which enables one to compute the number of rays participating in a burst in terms of the number of simultaneous discharges produced in any assigned number of Geiger counters arranged so as to receive some of the rays from the bursts. This expression is very fundamental in the interpretation of all experiments having to do with measurements of atomic bursts by Geiger counters. Then by an examination of the dependence of the frequency of occurrence of bursts on the sizes of the bursts, the Montgomerys have shown that there is no sharp line of demarcation between the so-called showers which are associated with but a few rays, and the bursts which involve thousands of rays. It has been customary formerly to think that the large bursts represented some phenomenon of a nature entirely distinct from that associated with the smaller bursts which have usually been referred to as showers. The Montgomerys have shown, in fact, that all of these bursts belong to one large family; and, by utilizing the mathematical expression to which I have already referred, and which they have derived, they have shown why it is that the former tendency to divide the bursts into two distinct classes is founded upon considerations which are largely illusory.

The Montgomerys have made measurements of the distance which the particles from an atomic burst can travel, and, among other things, have come to the conclusion that the burst particles are capable of traveling through approximately 11 centimeters of lead as a maximum. There is reason to believe that as we ascend into the stratosphere, more and more of the measured effects attributable to cosmic

rays are produced by secondary particles generated by the primary rays in the atmosphere itself. This is a matter to which I have already referred in speaking of theories of the nature of cosmic rays in relation to the measured effects. If in the stratosphere we have two ionization chambers, one shielded with lead and the other unshielded, then, in so far as the ionization in the chambers is produced by rays of the type associated with showers, the ionization in the shielded chamber should be less than that in the unshielded chamber by an amount calculable from the absorption of the showers in the lead. At the highest altitudes attained, in the stratosphere flight made by Commander Settle in 1933, Drs. Millikan and Neyer found a difference of 68 per cent. between the ionizations in shielded and unshielded vessels. The amount calculated by the Montgomerys on the basis of sea level measurements on the absorption of showers in lead of the thickness corresponding to that of the shield gives an absorption amounting to 62 per cent., which is in good agreement with the 68 per cent. reduction in ionization actually observed, and suggests that most of the ionization at these altitudes is produced by particles of the energy of the shower particles.

Another aspect of the work of the Montgomerys has been that of estimating the total energy associated with some of these showers. They find, for example, that many of the showers observed have in all an energy corresponding to more than that which would be obtained by an electron in falling through a potential difference of 30 thousand million volts.

MISCELLANEOUS INVESTIGATIONS.

I now turn to certain investigations not primarily concerned with nuclear physics but investigations having a significance bearing upon cosmic rays and atomic phenomena.

Passage of Cosmic Rays Through Magnetized Iron.—In former reports I have made brief reference to an experiment by Dr. Danforth and myself having to do with the deflection produced in the paths of charged particle cosmic rays in passing through magnetized iron, and the apparatus and method of procedure has already been described. It will suffice to remind you that as soon as physicists had gained the notion that cosmic rays were in some way associated

with high energy charged particles, the possibility of deviating the paths of these particles by causing them to pass through a magnetic field became immediately a subject of great interest. Our ordinary views of what electro-dynamics would have to say would have led us to believe that the deviation produced in a cosmic ray particle in passing through a suitable chosen piece of iron subjected to magnetizing forces would be about a 1000 times as great as it should be in the same magnetizing force if the iron were suddenly changed to wood for example. The first experiments which had been performed on this matter indicated that the iron had very little effect, if any. However, an analysis of the results of these experiments made by Dr. Danforth led to the conclusion that this drastic conclusion was unjustified. The experiments of Dr. Danforth and myself which have just been published led to the conclusion that the apparent deviation of the rays lay intermediate between that which would be obtained if the iron were ineffective and the value which would be predicted on the assumption that the iron exerted its full influence as demanded by classical electrodynamics.

In order to understand the meaning of these experiments I have been led to make a rather careful theoretical analysis of the situation prevailing in a piece of magnetized iron in its relation to the passage of cosmic rays through it. It turns out that the story is intimately bound up with the nature and size of that entity which is the fundamental little magnet which, in company with its fellows of the same kind, gives to the iron atom and to the iron as a whole its magnetic properties. If this entity is very small, a cosmic ray passing through a slab of iron of reasonable thinness would rarely come into contact with or pass through such an entity. If it did pass through this entity it would experience a very large deflection. It would be these very large deflections of cosmic rays, few in number, however, which would be responsible for making the true average deflection equal to that given by electromagnetic theory but which would nevertheless result in the practically measured average being much less than this. The situation may be taken as analogous to the following. Suppose we have a country of a hundred million people most of whom have on the average $1,000 a year. Suppose,

however, a hundred of these people have a thousand million dollars per year. Then the true average income of an individual is the one hundred thousand million dollars of the wealthy few plus the one hundred thousand million dollars of the majority of the people divided by the total number of people which is a hundred million. The average income is in fact $2,000. On the other hand if I start checking up banking accounts at random the chances that I encountered one of the very wealthy people would be extremely small and what I should practically find would be an average income of $1,000 a year. You will readily see that if I knew the number of the wealthy people but did not know how much they had, and if I determined the difference between the practically measured average income and the true average income, I could determine something about the incomes of the wealthy people. In analogous manner I have been able to show[12] that by experiments of the kinds which we have been doing and are doing, it is possible to obtain special information with regard to the nature of the fundamental magnetic entity.

Designs of Special Appliances, etc.—It is natural that during the course of our work we continually have occasion to develop methods and apparatus for our needs but of such a nature that these methods and appliances have a wider field of application. Dr. Locher, Dr. Johnson, and Mr. Ramsey have all developed Geiger counter systems suitable for the rapid detection of radioactive radiations and so for aiding the search for small quantities of radium which may happen to have been lost in hospital usage, etc.

One of the most useful things which has been developed during the year, for our own purposes, is a special form of liquid high resistance which is very constant in its characteristics. This has been developed by Dr. Danforth.

In addition to the foregoing matters many of us have been concerned with investigations of a purely theoretical nature having to do with nuclear physics, with modern atomic theory

[12] This investigation, and the corresponding experimental investigation, has been published since the report was presented. See W. F. G. Swann, *Phys. Rev.*, **49**, 574 (1936); also W. E. Danforth and W. F. G. Swann, *Phys. Rev.*, **49**, 582 (1936).

and the like. But this is no time of the evening to fill the blackboard with mathematics. Many of the investigations which I have cited, and some which I have not, have been published throughout the year, and those specially interested will find much fuller details in these publications.

APPENDIX.

PUBLICATIONS OF THE BARTOL RESEARCH FOUNDATION FROM APRIL 17, 1935 TO APRIL 15, 1936.

The Variation of Cosmic Ray Intensity with Direction in the Stratosphere—W. F. G. SWANN AND G. L. LOCHER. National Geographic Society Contributed Technical Papers, Stratosphere Series, No. 1, pp. 7–14, 1935; also reprinted in JOUR. FRANK. INST., **221**, No. 2, pp. 275–289, February, 1936.

Is the Universe Running Down? (Penrose Memorial Lecture)—W. F. G. SWANN. *Proc. Am. Phil. Soc.*, **75**, No. 3, pp. 217–249, July 1935; also published in Scientific Monthly, **42**, No. 6, pp. 498–516, June, 1936.

The Nature of the Cosmic Radiation—T. H. JOHNSON. JOUR. FRANK. INST., **220**, No. 1, pp. 41–67, July, 1935.

Progress of the Directional Survey of Cosmic-Ray Intensities and Its Application to the Analysis of the Primary Cosmic Radiation—T. H. JOHNSON. *Phys. Rev.*, **48**, No. 4; pp. 287–299, August 15, 1935.

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Nuclear Phenomena and Cosmic Rays—W. F. G. SWANN. *Ohio Jour. of Science*, **35**, No. 5, pp. 311–342, September, 1935.

Conservation of Direction in the Impact of High Energy Particles—W. F. G. SWANN. JOUR. FRANK. INST., **220**, No. 3, pp. 373–376, September, 1935.

Analysis of Cosmic Ray Deflection Experiments II—W. E. DANFORTH. JOUR. FRANK. INST., **220**, No. 3, pp. 377–386, September, 1935.

Report of Investigations Resulting from a Grant Made by the American Philosophical Society to W. F. G. Swann for Furtherance of Work in Nuclear Physics by Himself and His Collaborators—W. F. G. SWANN. *Miscellanea*, **1**, No. 1, pp. 21–47, September, 1935.

Cosmic Rays—W. F. G. SWANN. *Jour. Amer. Mus. of Nat. Hist.*, **36**, No. 3, pp. 255–261, October, 1935.

The Effect of Primary Cosmic-Ray Energy Upon Burst Production—W. F. G. SWANN AND D. B. COWIE. *Phys. Rev.*, **48**, No. 8, pp. 649–652, October 15, 1935.

The Corpuscular Theory of the Primary Cosmic Radiation—W. F. G. SWANN. *Phys. Rev.*, **48**, No. 8, pp. 641–648, October 15, 1935.

On the Showers of Rays Which Produce Bursts of Cosmic-Ray Ionization—C. G. AND D. D. MONTGOMERY. *Phys. Rev.*, **48**, No. 10, pp. 786–789, November 15, 1935.

Geiger-Counter Characteristics with Applied Potentials Reversed—D. B. COWIE. *Phys. Rev.*, **48**, No. 11, pp. 883–885, December 1, 1935.

The Variation with Altitude of the Production of Bursts of Cosmic-Ray Ionization —C. G. AND D. D. MONTGOMERY. *Phys. Rev.*, **48**, No. 12, pp. 969–970, December 15, 1935.

Contribution of the Cosmic Radiation to the Ionization of the Upper Atmosphere —T. H. JOHNSON. *The Transactions of the Amer. Geophysical Union*, pp. 35–37, Part I, December, 1935; also published in JOUR. FRANK. INST., **221**, No. 3, pp. 417–421, March, 1936.

Earth-Magnetic Analysis of the Primary Cosmic Radiation—T. H. JOHNSON. *The Transactions of the Amer. Geophysical Union*, pp. 171–175, Part I, December, 1935; also published in JOUR. FRANK. INST., **221**, No. 3, pp. 421–429, March, 1936.

The Measurement of Cosmic Ray Showers by Means of Geiger Müller Counters —C. G. AND D. D. MONTGOMERY. JOUR. FRANK. INST., **221**, No. 1, pp. 59–64, Jaunary, 1936.

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The Deflection of Cosmic Ray Charged Particles in Passing Through Magnetized Iron—W. E. DANFORTH AND W. F. G. SWANN. *Phys. Rev.*, **49**, No. 8, pp. 582–591, April 15, 1936.

A Theoretical Discussion of the Deviation of High Energy Charged Particles in Passing Through Magnetized Iron—W. F. G. SWANN. *Phys. Rev.*, **49**, No. 8, pp. 574–582, April 15, 1936.

Report of the Collection of Isotopes—L. H. RUMBAUGH. *Miscellanea, Amer. Phil. Soc.*, **1**, No. 2, pp. 50–51, April, 1936.

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Presented before the American Physical Society.

Baltimore Meeting, November 29–30, 1935.

Deflection of Cosmic Ray Secondaries by Magnetized Iron—W. E. DANFORTH AND W. F. G. SWANN.

Magnetic Spectrum of Positrons Generated in Lead by Th C″ Gamma Rays—G. L. LOCHER AND C. L. HAINES.

Theoretical Considerations Concerning Passage of Electrons Through Magnetized Iron—W. F. G. SWANN.

New York Meeting, February 21–22, 1936.

Automatic Coincidence Counter Measurements on Shipboard of the Cosmic Ray Latitude Effect—T. H. JOHNSON AND D. N. READ.

Magnetic Spectrum of Positrons Generated in Silver and Lead by Gamma Rays for Ra C—G. L. LOCHER AND C. L. HAINES.

Heavy Charged Particles as Primary Cosmic Rays—W. F. G. SWANN.

Washington Meeting, April 30–May 2, 1936.

Portable Counter-Controlled Wilson Cloud Chamber Machine of New Design—G. L. LOCHER.

A Search for Protons in the Primary Cosmic Ray Beam—C. G. AND D. D. MONTGOMERY, W. E. RAMSEY AND W. F. G. SWANN.

The Isolation of Lithium Isotopes with a Mass Spectrometer—L. H. RUMBAUGH.

Search for Nuclear Cosmic Ray Particles in the Stratosphere, Using Photographic Emulsions—L. H. RUMBAUGH AND G. L. LOCHER.

Cosmic Ray Measurements in the Stratosphere—W. F. G. SWANN.

Presented at the Washington Meeting of the American Geophysical Union, May 1, 1936.

Unidirectional Cosmic Ray Intensity and its Variation with Latitude—T. H. JOHNSON.

THE MECHANICAL SOLUTION OF SIMULTANEOUS EQUATIONS.

BY

JOHN B. WILBUR.*

I. SYNOPSIS.

Many problems encountered by engineers and research investigators in diverse fields are made cumbersome by the necessary solution of large numbers of simultaneous equations. The solution of such equations presents no theoretical difficulty, but as the number of unknowns to be obtained simultaneously, and, consequently, the number of equations to be solved, increases, the labor involved in their solution mounts rapidly.

Early in 1934, research was started at the Massachusetts Institute of Technology which has resulted in the construction of a machine for the solution of linear simultaneous equations with real coefficients. An experimental model of this machine was built in 1934, which, though mechanically crude, was so successful in its operation as to encourage the construction of a larger machine. The second machine, now in operation, was designed for the direct solution of nine or fewer simultaneous equations. It lends itself, moreover, to the solution of a larger number of equations, provided certain restrictions in their form are met. The theory upon which the machine is based is such that a larger machine capable of solving a larger number of equations directly may be built.

This research has been undertaken in the belief that a few such machines at educational or research centers, available for general use, will be of help in advancing progress in engineering and research.

II. THEORY UPON WHICH MACHINE IS BASED.

The theory upon which the machine is based may be explained by reference to the following set of simultaneous equations:

$$a_{11}x_1 + a_{12}x_2 + D_1 = 0, \tag{1}$$
$$a_{21}x_1 + a_{22}x_2 + D_2 = 0. \tag{2}$$

A single equation is reproduced mechanically as shown in Fig. 1. The coefficients a_{11} and a_{12}, and the constant term D_1 are set as distances on tipping plates, to the right or left of the plate pivot depending upon the algebraic sign of these

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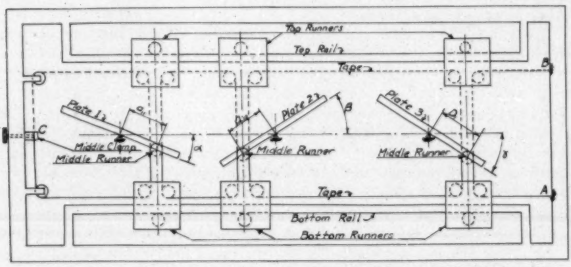
quantities. The equation is represented by a flexible steel tape, fixed at points A and B, and with a fixing clamp at C. That portion of the tape above the tipping plates (shown dotted) has as its function the maintenance of tension in the system during motion, and need not be considered further in an examination of the principles upon which the machine functions. The top and bottom runners, riding on horizontal rails as shown, ensure that the tapes leading away from the tipping plates will always be essentially vertical.

With the quantities a_{11}, a_{12} and D_1 set on their respective plates, let the three plates be leveled, and the clamp at C tightened so that no movement of the tape can occur at that

FIG. 1.



Elevation showing arrangement of plates and tapes for a two-equation machine.

point. If an angular motion is now introduced at any one of the three plates, there are, if only the action of the one tape shown in Fig. 1 is considered, an infinite number of positions which the other plates may assume. For any given position of the plates, however, the following equation holds, assuming that the total length of the tape between points A and C remains unchanged:

$$2a_{11} \sin \alpha + 2a_{12} \sin \beta + 2D_1 \sin \gamma = 0. \qquad (1a)$$

Dividing this equation by $2 \sin \gamma$ we obtain

$$a_{11} \frac{\sin \alpha}{\sin \gamma} + a_{12} \frac{\sin \beta}{\sin \gamma} + D_1 = 0, \qquad (1b)$$

which is equivalent to equation (1) if

$$\frac{\sin \alpha}{\sin \gamma} = x_1 \quad \text{and} \quad \frac{\sin \beta}{\sin \gamma} = x_2.$$

If now two tapes act simultaneously on these same three plates, and in the same manner as that just described, the distances a_{21}, a_{22} and D_2 being set on plates 1, 2 and 3, respectively, for the second tape, and if the same procedure is followed in first leveling all plates, and then introducing a certain angular movement at any one plate, the remaining two plates must undergo a definite corresponding rotation. The sine of the angles through which plates 1 and 2 have rotated give the values of x_1 and x_2 to a certain scale. The actual values of these unknowns are obtained by dividing their relative values by the sine of the angle through which plate 3, upon which the constant terms of the equations have been set, rotates.

III. DESCRIPTION OF MACHINE AS BUILT.

The machine as actually built consists of a heavy steel rectangular frame, within which rotate ten slotted steel plates (see Figs. 2, 3 and 4). Nine of the ten plates represent the nine unknowns for which the machine is built; on the tenth plate the constant terms of the equations are set.

Each plate has ten longitudinal parallel slots. In nine of these slots "middle runners" may be moved in order that the coefficients to the unknowns and the constants of the equations may be set. The tenth slot is utilized by a sine reading mechanism from which the sine of the angle through which a plate rotates may be read directly.

Nine tapes, each about sixty feet in length, represent the nine equations for which the machine is designed. The slots in which are placed the middle runners used for setting coefficients and constants of a given equation, and the tape which represents that equation, all lie in a vertical plane.

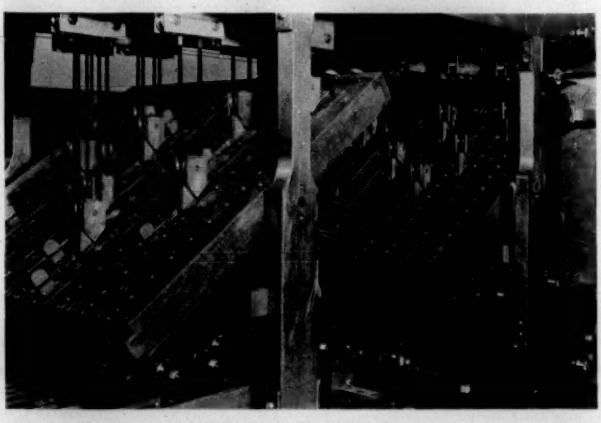
The middle runners may be unclamped, and moved freely to their approximate positions for the equations to be solved. Micrometer screws then enable one to make a setting to an accuracy of one two thousandth of an inch, which corresponds to four significant figures on the coefficient and constant scales.

FIG. 2.

Algebra in terms of metal. General view of new machine for solving simultaneous equations.

Inasmuch as the machine reproduces the equations geometrically, careful design and construction were essential. The frame itself is rigid so that it will not substantially distort elastically when operated. In order to minimize tape strains, over one thousand ball bearing pulleys are used, reducing friction to a practical minimum.

FIG. 3.

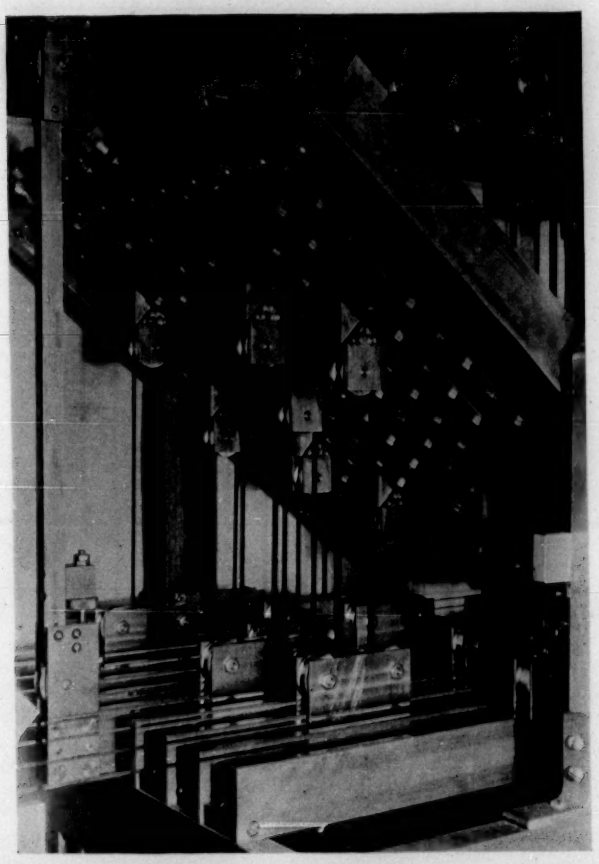


View showing upper side of tipping plate. The middle runners used for setting coefficients or constants on this plate, and corresponding top and bottom runners riding on their rails, may be seen.

IV. OPERATION OF MACHINE.

While the best technique for the operation of the machine has not been definitely established, the following outline will permit an estimate of the labor involved. The middle clamps (at "*C*," Fig. 1) are first loosened, which permits complete freedom of motion within the machine. The plates to be used are then approximately leveled, and all plates are clamped so that they cannot rotate. The coefficients and constants are systematically set on the proper middle runners and their settings checked. In the setting of these middle runners, most of the time required for solution is involved. The setting of a coefficient requires about the same time which

FIG. 4.



View showing under side of tipping plate. The under side of the middle runners for this plate, and the corresponding top and bottom runners riding on their rails, may be seen.

would be needed to turn off an angle on a transit. When these settings are complete, the middle clamps are tightened, only for the tapes in use, and the plates which are in use are unclamped. In this way it is possible to utilize only the portion of the machine required. Any of the plates involved in the solution of the given equations may now be rotated freely, but those plates which will undergo the largest rotations during solution will turn the most easily. Such a plate is found by trial, and used as the driving plate. This plate is rotated clockwise about 40 degrees, and brought to rest with an oscillating motion which tends to eliminate the detrimental effect of friction in the machine. As the driving plate is rotated, the other participating plates also rotate. The sine mechanism is then read on each participating plate. Driving the machine from the same plate, the plates are then brought back through their horizontal position until approximately the same motion has taken place in the opposite direction from that originally introduced, and again brought to rest with an oscillating motion. The sine mechanisms are again read. The value of any given unknown is then given by dividing the algebraic difference of the readings of the sine mechanism for the plate representing that unknown, by the algebraic difference of the readings from the sine mechanism for the plate upon which the constants have been set. Once the coefficients and constants have been set on the machine, the actual operation and interpretation of results require only a few minutes.

The total time required to solve nine simultaneous equations on the machine, to an accuracy of three significant figures, is estimated at from one to three hours, depending upon the equations themselves. This time will undoubtedly be reduced when more experience has been acquired in the technique of operation.

The solution of similar equations employing a keyboard calculator might be expected to require in the neighborhood of eight hours.

V. RESULTS OBTAINED FROM MACHINE.

The accuracy obtained in a given solution will depend upon the equations involved. Certain sets of equations,

bordering upon instability, will be difficult to solve, regardless of the method used, while other sets will yield excellent accuracy with little effort. The following two conclusions have however been reached:

1. For the usual set of equations, the errors in the values of the unknowns as given by the machine will not exceed one per cent. of the largest unknown, as read directly from the machine after one operation. In many cases, much better accuracy will result.

2. By successive approximations, arbitrary accuracy can be obtained. The machine is well suited to this procedure. If the results obtained from the first solution are substituted in the original equations and the corresponding constants computed, they will in general differ by a small amount from the actual constants of the equation. This difference is easily obtained with a computing machine. If now the equations are solved again, using in place of the constant terms in the original equations the differences in the constants thus obtained, the new solution yields the corrections to be applied to the unknowns as determined from the first solution. This procedure involves the re-setting of only the constant terms on the machine, hence progresses rapidly. It may be repeated successively to give results to any degree of accuracy required.

An important factor which greatly increases the scope of the machine is the development of a method whereby more than nine equations can be solved by the machine. This expansion is limited by the form of equations which can be thus solved, but it is nevertheless applicable to many important problems. The usual type of simultaneous equations encountered by the structural analyst in the investigation of stresses in an indeterminate structure furnishes an example of the type which can be solved in this manner by the machine. In the development of this use of the machine, eighteen simultaneous equations resulting from a slope deflection solution of a building frame acted upon by lateral loads were solved with an accuracy of between four and five significant figures. It is estimated that under the proper conditions a machine solution of this kind would take seven and one-half hours. The time required for a corresponding solution by a

keyboard calculator is estimated at 32 hours. As the number of unknowns increases, the time saved by mechanical solution becomes increasingly important.

VI. FUTURE INVESTIGATIONS.

Our research on this type of mechanism is by no means complete. Minor changes in the present machine are contemplated. More exhaustive tests will undoubtedly show that the tapes now on the machine have neither the optimum flexibility nor initial tension. The technique of operation is as yet imperfect. There is every reason to believe that the accuracy as obtained from a single set of readings can be improved.

The relative success of the present machine indicates that a machine capable of directly solving a larger number of equations is feasible. The development of an automatic means of setting coefficients and constants would add greatly to the practicability of a larger machine, leading to large savings in time of solution.

VII. ACKNOWLEDGMENT.

In a development of this kind, the one responsible for the continuity of effort, while contributing to the final results, acts largely as a clearing house for the ideas of those who work with him. Space does not permit complete acknowledgment of the help that has been given. To Dr. Vannevar Bush, Vice-President and Dean of Engineering at M. I. T., however, much of the credit for the success of this enterprise is due. His original interest in the research, his contribution of several basic ideas, together with his continued interest and suggestions, have made the development possible. To Sir Douglas Alexander, President of the Singer Sewing Machine Company, grateful acknowledgment is tendered for having made the construction of the new machine possible. To Professor Charles B. Breed, Head of the Civil Engineering Department at M. I. T. under which this research was conducted, the writer owes a debt for his interest and friendly encouragement.

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STEAM IN RELATION TO MARINE ENGINEERING.*

BY

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Chief, Bureau of Engineering, U. S. Navy.

First, I wish to express my sincere appreciation of the honor accorded me in representing the Navy and the Marine Engineering Profession in general before this distinguished gathering tonight. On this 200th anniversary of the birth of James Watt, it is fitting for all who have profited by the product of his genius to express something of the deep respect and admiration we all feel for the work of that great pioneer of our Mechanical Age. His genius and initiative have contributed profoundly to the amazing developments of the past 100 years, in both the mechanical and electrical fields, and have been a constant source of inspiration to others to follow along the path he defined.

I believe that I may confidently state that in the marine field such developments have been completely revolutionary in character and have changed the whole trend of human endeavor. More emphatically, I may say that the history of civilization has been changed radically thereby. Whether for the better or for worse I cannot positively state. If greater comfort, higher living standards and a general speeding up of the tempo of life in general may be considered as a criterion of advancement then the change is for the better; but whether the entire sum of human happiness has been increased by these changes, I hope that I may be pardoned for expressing a reasonable doubt.

In my own life I have witnessed the final passing of sail, today practically complete. The billowing canvas and the picturesque top hamper of the sailing vessel have given way to the belching smoke pipes; unadorned masts and the drapery

* Address delivered at the dinner held under the auspices of The Franklin Institute on the occasion of the observance of the Two Hundredth Anniversary of the birth of James Watt, Tuesday, January 21, 1936.

of radio antennæ. The sooty path or the oil slick of the steamer has penetrated and made commonplace the most remote corners of the Seven Seas. Something of romance, something of mystery, that fired the imagination of our race, has been lost. Something of a more practical nature has been lost too. The propulsive equipment that once soared above the useful space on decks and below has now descended bodily into the hull structure itself and, by its presence there, together with the fuel required for its operation, competes seriously with the demands of the useful load. The time of passage from port to port is now a mere fraction of that required by sail and the leisurely ways of the past are almost forgotten. However, this has not been without compensation for there are many among us who find a fascination and an interest in the operation of a smooth-running perfectly balanced machine with its appeal to the imagination beyond the power of any other inanimate object.

The fact that the presence of modern propulsive machinery and the fuel for its operation is a regrettable necessity in the hulls of modern vessels, commercial or naval, has created really the profession of the marine engineer and has at the same time made that profession an unenviable one. For the space occupied by that machinery and its weight, together with that of the necessary fuel, constantly infringes upon the demands of the useful load whether it be for the cargo and passengers of the commercial vessel or for the armor and armament of the naval vessel. However, the trials and tribulations of the modern marine engineer cannot be laid at the door of James Watt for that shrewd individual was firmly opposed to two major developments in the latter course of his life, namely, the application of the steam engine to transportation and the constant increase of steam pressure.

I believe that the greatest single contribution to modern marine engineering of this wonderful pioneer consisted in his first separating the condensing operation from the working cylinder. The invention of the jet and surface cooling principles of condensation and the wet air pump were also his. Among others, must be mentioned the piston rod stuffing box, the double acting cylinder, steam jacketing, the steam admission valve with its cut-off, utilizing the expansive

power of steam, and the indicator. All such innovations are in use today—more than 100 years later, and have been the basis for the development of all reciprocating equipment including the internal combustion engine. In view of the bitter battle today between the steam engine and the internal combustion engine, the last point will not be conceded possibly by the internal combustion designers.

The invention of the steam vessel itself has been claimed for one Spaniard, one Frenchman, one Englishman, two Scotchmen, and four Americans. Among these you can take your choice depending upon which nationality you favor. Furthermore, practically every industrial country has its own inventor of the screw propellor. Even the invention of the tubular boiler is claimed by no less than four. It does not appear profitable to enter into a discussion before this intelligent audience of the proper ownership of these honors. In this country, however, we find the beginning seems to have been made with John Fitch's brass model fitted with wooden side paddle-wheels presented to the American Philosophical Society of Philadelphia in 1785. This model was followed three years later by his commercially successful stern paddle-wheel steamer. It seems appropriate, too, to mention at this point that a twin screw cross geared vessel with a water tube boiler was produced by Colonel John Stevens of Hoboken, a friend of Fitch's, in 1804, and operated on the Hudson. It is claimed that 50 pounds pressure was used on this vessel. A later vessel of Stevens' design, the "Phœnix," was driven by Fulton out of the Hudson River and down to Philadelphia and is claimed to be the first sea-going steam vessel. In 1806 came the slower but much better known "Clermont" of Fulton. Fitch's machinery and that of Stevens was of American manufacture, but, we must admit, the machinery of Fulton was of Boulton and Watt's best design, with Watt's "wagon type" boiler, made of copper and carrying 5 pounds pressure.

From these crude beginnings, the development was comparatively slow, gaged by more recent progress, and the designs for many years featured mainly Watt's vertical beam engine and Fitch's paddle-wheels with steam generated in horizontal large flue boilers. Boilers gradually became

cylindrical as pressure reached 30 pounds and in 1850 one marine boiler is listed at 80 pounds and one at 90 pounds. About 1851 Erasmus Smith designed, and Mott and Ayres of New York built a horizontal return tube cylindrical marine boiler with the so-called "wet-uptake"—the first known example of the familiar "Scotch" type of boiler. Randolph and Elder of England followed in 1862 with the first double ended "Scotch" boiler.

As previously stated, the credit for the first water tube boiler appears to belong to Colonel John Stevens of Hoboken. Stephen Wilcox placed the first Babcock and Wilcox water tube boiler on the yacht "Reverie" in 1889. William Hoxie improved this design with one installed on the U.S.S. "Alert" in 1895. And one must not forget the installation by Admiral Melville of Charles Ward's water tube coil boiler on the U.S.S. "Monterey" in 1893.

It is believed that Randolph and Elder of England should also be credited with the first successful compound reciprocating marine engine which was designed and built in 1854. This design utilized double the previous steam pressures which had remained at from 15 to 20 pounds. Superheating came in about 1870 with 60 pounds steam pressure, but was ultimately abandoned to be developed years later by the Babcock and Wilcox Company. In 1875 came the first triple expansion reciprocating marine engine with demands for higher pressure steam until 180 pounds was reached.

Development in the marine propulsion field was very rapid from that time on, following improvements in reciprocating engine and boiler designs until 1897 when Sir Charles Parsons "stole the show" with his yacht "Turbinia" presented at the Naval Review in 1897, celebrating Queen Victoria's Diamond Jubilee. The death knell of the marine reciprocating steam engine for use in high speed, high-powered modern vessels was sounded then and there. The marine reciprocating engine based on Watt's fundamental designs probably reached its peak in the design of the German "Kaiser Wilhelm, Second" in 1903, with twin quadruple expansion, steepled cylinder engines developing 38,000 indicated horsepower. Many will remember this latter vessel and its sister ship, the "Kronprinzessin Cecilie," when they were engaged in trans-

porting our troops to France during the World War, but renamed by us the "Agamemnon" and the "Mt. Vernon." In our own Navy the reciprocating engine reached its peak in our battleship design with 28,400 indicated horsepower. These engines on the battleships "New York," "Oklahoma," and "Texas," are still in service.

The pioneer commercial turbine-driven vessel of the merchant marine was the "Victorian" of the Allan Line, using a direct turbine drive and put in operation in 1904. This was followed by the "Virginian" in 1905 by the same Line and later by the Cunard Liner "Carmania" in 1906. At the time of the construction of the "Victorian" 400 tons was the estimate for the saving in weight of the machinery installation over that of an equivalent reciprocating engine equipment—this with a fuel consumption equal to the best the reciprocating engine had ever produced.

Following experimentation with the yacht "Charmian," the British Admiralty contracted with the Parsons Marine Steam Turbine Company in 1898 to provide turbine machinery for the destroyers "Viper" and "Cobra," both of which were outstandingly successful on trials. These vessels were, unfortunately, lost at sea in 1901. The "Velox," having four screws with cruising reciprocating engines, followed and became the first example of a marine reciprocating steam engine exhausting into a turbine. Under the British Admiralty the "Amethyst" in 1904 was the first turbine cruiser and the "Dreadnaught" in 1906 was the first turbine battleship.

In the meantime, Mr. Charles G. Curtis, under patents granted in 1896, was perfecting in the United States his pressure staged and velocity compounded impulse turbine design. The first vessel built having this type of turbine is believed to have been the yacht "Revolution," completed in 1902, but which was not very successful, primarily due to poor model design.

In our Navy the steam reciprocating engine long remained as the most reliable propelling equipment. The battleship "North Dakota" of 1908 was the first capital ship to have direct drive Curtis turbines, but lack of reliability and small cruising radius resulted in the construction of the battleships

"New York" and "Texas" in 1912, and the "Oklahoma" in 1914, with reciprocating engines. However, a sister ship of the "Oklahoma," namely the "Nevada" was fitted with Curtis turbines and geared cruising units. These two latter vessels also marked the definite shift from coal to oil fuel in our Navy.

It may be of interest at this time to recall two major engineering experiments conducted at about this time by our Navy. The first was with the cruisers "Birmingham" "Chester," and "Salem." The "Birmingham" had twin screws fitted with triple expansion reciprocating engines. The "Chester" had Parsons direct drive turbines on four shafts and the "Salem" had Curtis turbines on two shafts with single reduction gears. This first experiment was not especially successful in demonstrating the superiority of the turbine, as the reciprocating engine vessel had a more economical performance at full power. Later, three fuel carrying vessels of the 1911 program were separately engined as follows: the "Cyclops," a twin screw vessel, with reciprocating engines; the "Neptune," two shafts with Parsons turbines and Westinghouse reduction gears; and the "Jupiter," two shafts with a Curtis turbine generator driving two electric propulsion motors all of General Electric design. The "Jupiter" thus became the first electric drive vessel and is still in service today, though renamed the "Langley."

It seems appropriate at this point to pay tribute to the outstanding contributions made to the development of the turbine electric marine propulsion equipment by Mr. W. L. R. Emmett of the General Electric Company; also Rear Admiral Hutch I. Cone, Chief of the Bureau of Engineering from 1909–1913; the late Rear Admiral Robert S. Griffin, Chief of the Bureau of Engineering from 1913 to 1921; Admiral S. S. Robison, Commanding Officer of the "Jupiter" in 1914, and Rear Admiral S. M. Robinson, first Engineer Officer of the "Jupiter," all of the U. S. Navy.

The experimental installation on the "Jupiter" was so generally successful that turbine electric propulsion was adopted for capital ship construction in the U. S. Navy, beginning with the battleship "New Mexico," in 1917, and all later battleships have followed the same design. The highest

powered vessels in the U. S. Navy today have electric propulsion, namely, the aircraft carriers, "Lexington" and "Saratoga," with 180,000 shaft horsepower each. In the merchant marine, turbine electric drive has not been widely used although recently we have all noted the performance of the "Normandie" of the French Line, the highest powered merchant vessel now in operation, which is equipped with turbine electric propulsion of 160,000 shaft horsepower at full power. The British merchant marine has used the turbo electric drive design on several important vessels such as the P. and O. liners of the Strathnaver type using 28,000 shaft horsepower, though the latest design on this service, as shown by the "Strathmore" of 1935, is a geared turbine arrangement. Our own merchant marine has employed electric drive up to 26,500 shaft horsepower for the "President Hoover" and "President Coolidge." But later designs now contemplated employ geared turbine drive.

Nothing in the history of marine engineering can equal the rapid changes in marine propulsion which have followed the coupling of the turbine to reduction gearing, both single and double, and the development of turbo-generators with main shaft driving motors. Both these methods utilize to the utmost the inherent advantages of high speed turbines while still retaining the more efficient propeller speeds. Steam pressures and temperatures have increased rapidly, far beyond anything that could have been used to advantage with reciprocating engines; at the same time that the horsepower of vessels has been enormously increased, fuel consumption per horsepower has been decreased thus making it possible to greatly increase the speed of sea-going vessels without infringing on the space and weight required for the useful load. And with all this has come a flexibility of control and a reliability of operation closely paralleling that of the reciprocating steam engine itself which over the years set a standard of reliability that may never be approximated again.

Above all other characteristics of marine machinery, the marine engineer must of necessity put reliability first. Failure of power ashore may occasionally be a serious matter, but it is more likely to be merely a troublesome inconvenience, or at the worst, result in a slight economical loss. Repair facilities are

immediately at hand and the entire industrial equipment of the country is readily available at a price. Not so if power failure occurs at sea where great loss of property and even serious loss of life is frequently a consequence. Consider too the case of the naval vessel, built for one purpose and one only, to defend the Nation against aggression. If such a vessel fails in a crucial moment of a Naval engagement, probably a matter of a few moments or hours at the most, it is worse than a failure—its very construction at all was a menace to the national welfare. Hence, the Naval engineer must always visualize the possible Naval battle for which a Naval vessel is designed and give reliability precedence over all other considerations, even at the expense of economical operation, space and weight. Building fighting vessels within tonnage limits set by International agreement, with each Nation striving to include the maximum offensive and defensive capabilities within such tonnage limitations, taxes the marine engineering talent of every modern Naval power to the utmost degree. Economy of operation and space and weight requirements have been, during the recent past, just as important in the design of the military ship as in the case of the commercial vessel, but with the added reliability factor demanding infinitely greater consideration. Someone can always be found to underwrite commercial ships and cargoes against loss at sea, but only a Divine power can underwrite the Naval vessel or the Nation which it defends.

It may be well at this point to glance briefly at some design results which indicate progress in Naval engineering in recent years. Considering battleships first, it should be pointed out that none have been built since the Washington Treaty. The design of battleships now in service placed reliability before all other considerations, and this is reflected in the weight of the machinery per horsepower. The average weight per horsepower of battleship propulsion machinery, including all auxiliaries, piping, wiring and electrical equipment complete, before the advent of turbines was about 230 pounds per horsepower. The use of geared turbines reduced this to about 180 pounds per horsepower. The use of the turbo-electric propulsion equipment, however, raised this figure again to about 200 pounds per horsepower, but in the case of high

powered turbo electric drive vessels, such as the "Saratoga" and "Lexington," this figure was reduced to less than 100 pounds per S.H.P. Until we reach the re-engined battleships the fuel consumption of this class of machinery has not been materially better than about 1.2 pounds per S.H.P. hour for all purposes, except in the case of the turbo-electric propulsion equipments which closely approximated 1 pound per S.H.P. hour. Recent improvements in the re-engined battleships, however, have reduced this consumption with geared turbine designs down to approximately .9 pound per horsepower hour.

In the cruiser class of vessels, the difference is much more marked. The "Birmingham," for example, with reciprocating engines required 123 pounds per S.H.P. whereas our modern cruisers with turbines and reduction gearing approximate 40 pounds per S.H.P. Fuel consumption for this class of vessels has also improved down to approximately .7 pound per S.H.P. hour. For the destroyer class improvements have been still more marked until today we are building destroyers with propulsion machinery approximately 30 pounds per S.H.P. and with fuel consumptions equal to or better than that of the cruisers.

Today we are using steam pressures up to 600 pounds and temperatures up to 700° F. in the Navy and higher temperatures are in use in the commercial marine field. This, it is realized, is very conservative as compared to practice ashore, but this is due to the natural conservativeness of marine design. Still higher pressures and temperatures afloat will arrive, however, in the course of time.

It would not have been possible to have so greatly increased the power of vessels were it not for the substitution of fuel oil for coal. In this country the maximum reached has been in the "Saratoga" and "Lexington," mentioned previously, with 180,000 S.H.P. each. Try to imagine what it means to concentrate such a tremendous amount of flexible power in the space available in the hull of a fighting vessel where every pound and every cubic foot of propulsive machinery competes directly with every pound and every cubic foot of armor, armament, ammunition, airplanes, bombs, gasoline, and living quarters. The genius of James Watt would find a generous field for endeavor if its like were available in the world today.

The traditions and many of the mechanical principles of the reciprocating steam engine are still carried on today in thousands of applications afloat in the less important and low powered designs and, combined with the low pressure turbine, may even compete in important future commercial installations. But the internal combustion engine utilizing many of the conventional design features originated by Watt is now just coming into its own and is competing seriously for supremacy in the field which the advent of the turbine preempted from the reciprocating steam engine.

Our design horizon is now primarily limited by the fundamental limitations of the metals with which we work. The genius of our research workers is constantly widening this horizon by the elimination of many of our uncertainties. The boiler, the turbine and the internal combustion engine are making demands upon metallurgists for better and better materials in order to achieve heights of power and dependability beyond anything conceived today.

The internal combustion engine challenges seriously the best that boilers and turbines can offer in the marine propulsion field, at least up to about 15,000 S.H.P. This challenge is primarily expressed as an advantage in economy of fuel. But the forced circulation boilers with extremely high pressures and temperatures of steam combined with turbines which can utilize steam with such characteristics are rapidly paralleling the performance of internal combustion engines and may always be expected to compete. In some fields the internal combustion engine is supreme today, primarily perhaps for the submarine type of vessel, for which no other type of drive can seriously be considered. The light, high speed Diesel engine with suitable arrangements for eliminating dangerous criticals is now dominating certain low power fields. New designs in steam equipment, however, are only a short way behind. The future—what can I say of the future! What can anyone predict as to future developments in this mechanical age of ours as one contemplates the tremendous changes that have taken place since the day of Watt, and particularly during the past 20 years.

I believe that the immediate future will be dominated by steam for marine installations of 10,000 to 15,000 horsepower

and higher, including all express liners and combatant vessels of war. Great potentialities exist in the extra high pressure boiler designs such as the Velox, the Loffler, Benson, and Wagner types of forced circulation boilers now being installed more or less experimentally abroad. This country too is rapidly developing designs of similar characteristics. Probably steam pressures will not exceed 700 to 850 lbs., but temperatures will only be limited by the limitations of metal. Much further experimentation is necessary before the full capabilities of extra high pressure steam can be realized in installations afloat. But, in any case, the signs all point to the fact that steam propulsion is just now entering a completely new development stage which may lead us as far from our present day designs as we have already advanced from the time of James Watt. I thank you.

Air Conditioning for Infants and Others.—(*Gas Age Record and Natural Gas*, Vol. 78, No. 12.) A 26 per cent. saving in the lives of premature babies by air conditioning was reported to the Harvard Tercentenary by C. P. YAGLOU of the Harvard School of Public Health. Artificial weather equipment is supplanting incubators and supplements all other treatments because it guarantees proper humidity and circulation as well as uniform temperature. Mr. Yaglou stressed the importance of proper humidity, saying that the greatest life saving appeared with relative humidities of 50 to 75 per cent. Humidities of 25 to 39 per cent. saved the lives of 9.7 per cent. more babies, while 50 to 75 per cent. humidities raised the saving to 26.5 per cent. Why humidity is so important could only be inferred and one inference is that premature babies are not ready for normal dry atmosphere. He also recommended higher humidities in operating rooms to preclude any possibility of a spark igniting anesthetics. Another hospital need is air conditioning for patients immediately after operations during heat waves. Heat sometimes causes serious post-operative shock.

R. H. O.

TUBULAR CANTILEVERS.

BY

LIEUT.-COMMANDER W. P. ROOP, C.C., U.S.N.

Data contained in recent papers by Lundquist, are herewith summarized in the form of a diagram. The very comprehensive collection by Heck and Ebner of formulæ and references for use in design of thin metal structures happens not to include the case here considered, which is that of a cylindrical tube of unstiffened metal of uniform thickness. The ends are fully constrained to retain their circular form. The load is transverse, and the reactions are those of a simple cantilever.

Symbols are as follows:

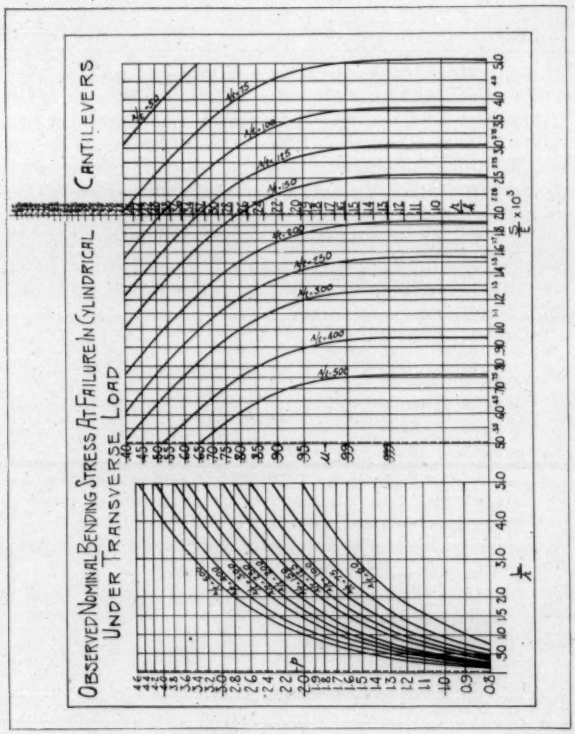
t = wall thickness.
L = length of tube.
r = radius of tube.
h = length of cantilever = M/V.
These 4 lengths are expressed in the same units.
V = transverse load in pounds, equal to total shear on transverse section; specifically, the value at failure.
M = moment-load in inch-pounds; specifically, the value at the base of the cantilever at failure.
S = bending stress in pounds per square inch due to M at failure in the cantilever.
E = Young's Modulus.

Two parameters are utilized; these are

$$p = .226\left(\frac{L}{r}\right)^{.5}\left(\frac{r}{t}\right)^{.35}$$

and

$$u = \left(1 - \frac{p^2r^2}{h^2}\right) - .5.$$


Observed Nominal Bending Stress At Failure In Cylindrical Cantilevers Under Transverse Load

DIRECTIONS FOR USE OF THE CHART.

(*A*) To determine transverse load at failure when r, t, h, and L are given.

(*a*) Enter the left part of the chart with L/r and r/t and take out p.

(*b*) Align p with $\frac{r}{h}$ on the extreme right and take out u.

(*c*) Enter the right part of the chart with u and r/t and take out S/E. If S exceeds yield point, use that.

(*d*) Multiply S/E by the value of E and by the section modulus of the cylinder, $\pi r^2 t$, to obtain moment-load at failure and divide this by h for the transverse load at failure.

(*B*) Given r, h, L and S, to find thickness required.

(*a*) On the given value of r/h work a straight edge by trial until the value of r/t is the same in the two sets of contours, one on p and L/r and the other on u and S/E.

(*b*) Divide r by r/t to obtain t.

(*C*) Given r, h, and L, to determine thickness required to withstand a given load M.

(*a*) Assume a value of thickness, t_1, and proceed as in (*A*), (*a*) to (*c*), to find nominal stress at failure, S. Use yield point if exceeded by this nominal value.

(*b*) Divide load (moment) by $\pi r^2 S$ to obtain t_2.

(*c*) Average t_1 and t_2 to obtain a new value t_3, and proceed as in (*a*) to obtain successive approximations.

(*D*) To find most effective radius, when L, h, and load are given.

(*a*) Assume a series of values of r suited to the requirements. For each find S and t as in (*C*).

(*b*) Tabulate values of rt, to which weight of cylinder is proportional, and seek the minimum value.

(*c*) In case S falls below the yield point, consideration may be given to use of stiffeners on the plating.

In preparation of this chart, the curves given by Lundquist have been the principal resource. These are based largely on Lundquist's own tests, although data from other sources are also included, as indicated by Lundquist's references.

In addition the chart has been checked against unpublished data and found to furnish a useful basis for design.

The data on which the chart is based are experimental, and subject to a certain amount of variation or tolerance. Strength as predicted by the chart was often exceeded; in a few cases of obviously poor fitting, the actual strength fell below the chart value. Data taken from the chart are thus conservative, but provide no margin for poor workmanship. Examination of the references will show that data obtained under different types of loading are rather widely scattered.

Allowance for the effects of shear, for the instability of the cylindrical plating, for the difference in action of the plating in bending compression as compared with direct compression, need not be made as these effects were all present in the tests. But allowance for the effect of loads other than that assumed, for example for torsional or direct compressive loads, must be made separately.

The values of bending stress herein considered are the nominal values at failure, obtained by direct application of the simple bending formula. To avoid confusion, it is preferable to put safety factors in terms of load rather than stress. The loads V and M should thus be taken as working values times safety factors.

Comparison of calculated stress value with stress limits of the material need thus be made only if the nominal stress at failure, as indicated by the chart, exceeds the yield point of the material, in which case the yield point should be substituted for the nominal stress at failure. On this basis the safety factor indicated for use will be that commonly obtained by dividing the calculated working stress into the yield point. For more precision use may be made of the modulus of rupture as found by bending test on the given material in moderate thickness, instead of yield point.

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The Nemours Carillon Tower.—(*Heating, Piping and Air Conditioning*, Vol. 8, No. 10.) The late Alfred I. DuPont in seeking a suitable memorial to his mother and father, determined upon the campanile, or bell tower, as an ideal type of structure. Containing crypts for family burial, it would also give pleasure to the public by its architectural beauty and the musical excellence of its bell chimes. An original design was created in harmony with surroundings. The tower is approx. 210 ft. high and is located on the DuPont estate, Nemours, overlooking Wilmington Del. The foundations go down to solid bed rock. From the center of a spacious terrace the shaft of the tower rises majestically. Although square in form, its corners are chamfered with a slight taper upward. Below the cornice at the first floor level the walls are finished in gray Vermont marble. Above that is cast stone, the corners being gray and the panels a delicate pink. A belfry surmounts the main shaft and is crowned by a delicate, tapering wire tipped by a bronze cross. Because of the character of the tower structure and in keeping with the desire to have every detail of the type most suited to the service, electricity was selected for all heating, lighting and power purposes. Unique heating problems were presented. Heaters were recessed in the walls and a special design was worked out with a motor driven blower operating at low speed to insure extreme quiet. The temperature of each room is controlled independently by a thermostat. Special treatment was required for certain rooms (such as the music room) where it is necessary quickly to bring the temperature up to 70 deg. for the comfort of visitors and the musician playing on the keyboard of the carillon. There are many other interesting features such as floodlighting, lightning protection and airplane beacon lights.

R. H. O.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

PLASTICS IN BUILDING CONSTRUCTION.

The following is the abstract of an address by G. M. Kline, chief of the Bureau's section on organic plastics, at a meeting of the Federation of Architects, Engineers, Chemists and Technicians, on October 5 in Washington. Organic plastics have become familiar to everyone because of the many useful objects fabricated from them which are found in every modern home. Radio housings, French phones, and electrical devices molded of phenol-formaldehyde resin; bright colored clock cases, table accessories and bathroom fixtures of urea-formaldehyde resin; vanity sets and powder containers of cellulose nitrate; lamp shades and pen and pencil sets of cellulose acetate; buttons and buckles of casein—these are but a few of the plastic products which we make use of from day to day. Plastics now seem destined to find still wider use in the home and in the building industry in general. In laminated form these materials are finding important applications, for interior and exterior trim and several new manufacturing units have been organized recently to meet the growing demand. Installations have been made in theaters, hotel lounges and bars, banks, and aboard the *Queen Mary*, and the material is to be utilized on a large scale in the Library of Congress annex at present under construction.

It is of interest, therefore, to consider the method of manufacturing laminated plastics, the advantages which they offer as a building material, and the various purposes for which they have been used.

A laminated plastic is made up of a fibrous filler in sheet form, such as paper, linen and canvas, and a resin binder, usually of the phenol-formaldehyde type. The individual sheets of filler are impregnated with a solution of the resin, dried, and a sufficient number pressed between steam heated platens in a hydraulic press to give a hard, dense product of

* Communicated by the Director.

the required thickness. Usually a relatively thin sheet of the laminated plastic is applied as a veneer over a less expensive base of pressed board or plywood.

The outstanding advantages which the laminated plastics offer as building materials are superior properties, attractive decorative possibilities, ease of prefabrication, and simplicity of application. The properties which have been of prime importance in the selection of these plastics by architects and builders are their unusual resistance to wear and to corrosion by moisture, acids, alcohols, alkalies and other deteriorating agents; their excellent mechanical strength; and their dimensional stability. They are available in a practically unlimited range of colors, which go through to the subsurface layers, and the permissible choice of transparent, translucent, mottled, or opaque finishes makes possible a variety of decorative effects. Prefabrication at the factory with no period of seasoning nor additional treatment to resist corrosion are noteworthy features of the material. The simplicity of installation, which requires only one craftsman, a carpenter, and the complete absence of obnoxious odors or of the possibility of chance spotting or staining enables modernization of existing structures to be accomplished during those hours of the day in which the establishment is normally closed.

Many of the applications of laminated plastics can be traced to the smart atmosphere which they create. They have been installed in restaurants, bars, cocktail lounges, department stores, hospitals, and hotels as table and counter tops, for which their warmth, resistance to staining, cigarette-proofness and noise-deadening characteristics are decidedly advantageous. Many theaters, hotels, and banks have used laminated plastics for wall and ceiling panelling because of their attractive appearance, durable finish, and ease of cleaning. The use of laminated plastics for doors achieves both beauty and permanence. Where regulations require fireproof construction, this can be attained without limiting the architect in choice of color or design on the face of the door. Exterior applications have not been as extensive as those for interior decoration. However, store front bulkheads and display signs have been constructed of this material

by progressive manufacturers who wished to reach a potential market in which style and smartness would be assets. The resistance to moisture, lack of any tendency to crack because of sudden changes in temperature, and the retention of the original finish indefinitely have been cited as major advantages of the laminated product for such purposes. The architectural uses of laminated plastics in the home and club, office and public building may be expected to increase rapidly in line with the tendency to modernize surroundings to obtain beauty, simplicity, and utility.

CARE OF FILMSLIDES AND MOTION PICTURE FILMS IN LIBRARIES.

Reference libraries of the future may contain files of photographic films in addition to shelves of the conventional books, if the present tendency to employ this modern method for recording and copying the printed word continues. Hence, it appears that librarians, long the custodians of valuable books and papers, are to be confronted with the problems involved in the care of records on photographic films. Some of these problems have been studied at the Bureau, and a report by C. G. Weber and John R. Hill will be published in the November number of the *Journal of Research* (RP942).

The film used for records is of the safety type, and is no more flammable than books; hence it offers no new problems in fire protection. It is very stable chemically and should be lasting if properly made and stored. Safety film, however, is quite sensitive to moisture changes and is brittle when dry, satisfactory service requiring that the moisture content be controlled by air conditioning in the storage rooms or vaults.

The ordinary type of motion picture films have a base of cellulose nitrate which is highly combustible. The storage of this type of film presents difficult problems of fire protection, and should be undertaken only by persons entirely familiar with the necessary precautions.

INKS FOR RECORDING INSTRUMENTS.

Instruments for making continuous records of temperatures, steam or barometric pressures, electric voltage, etc.,

must sometimes go for a long time without attention. The record is made on a circular chart, or on a long roll of paper, and there must be an ample supply of ink of a kind that will not dry and clog the pen. Glycerol (glycerin) is practically nonvolatile at ordinary temperatures, and it tends to absorb moisture from the air, so it is used for making inks for recording instruments, as well as for rubber stamps. For years, the United States Weather Bureau has used recording inks made by dissolving dyes in a mixture of equal volumes of water and glycerol. Although this mixture is a good "anti-freeze," yet there are parts of this country in which it would be frozen solid outdoors during the winter. This is prevented by adding enough alcohol to still further lower the freezing point of the ink. For recording instruments indoors, it is better to make the ink with a mixture of one volume of glycerol and three volumes of water.

Because the glycerol does not evaporate, the ink must dry on paper by being absorbed. The ink not only sinks into the paper, but it also spreads sidewise from the marks made by the pen. If there is too much spreading, the edges of the lines will be uneven or "feathered." Dr. C. E. Waters of the Bureau has recently made tests of a number of recording inks, prepared by dissolving dyes of different types—acid, basic, and direct—in the two mixtures of glycerol and water. The inks were tested by drawing lines with them on five kinds of paper, including the charts regularly supplied with three kinds of recording instruments. After the lines dried, they were rated according to their appearance as nonfeathering, slightly feathering, and decidedly feathering.

In all, 190 lines were drawn with 38 inks, made from 19 acid and basic dyes, on five kinds of paper. Of these, 72 were rated as decidedly feathering, 108 as slightly feathering, and only 10 as nonfeathering. The proportions of glycerol and water, whether 1 : 1 or 1 : 3, made little difference in the results. Sixteen "direct" dyes, which are taken up directly by vegetable fibers, without the aid of mordants to produce insoluble compounds with the dyes, made a far better showing as recording inks. The 32 inks made with these dyes were used for drawing 160 lines on the five papers. Of these, 131 were rated as nonfeathering, 22 as slightly, and only 7 as

decidedly feathering. Evidently the dyes were taken up by the fibers of the paper before they could get more than a minute distance from the lines as they were drawn.

Ethylene glycol is similar to glycerol in many of its properties, but is somewhat more fluid. Inks were made by dissolving the 16 direct dyes in mixtures of glycol with 1 and 3 volumes of water. They showed more feathering than the inks made with correspondingly diluted glycerol. With both sets of solvents, the inks containing 3 volumes of water showed the least feathering.

The complete report of these experiments will be found in the November number of the *Journal of Research* (RP935).

CHANGE OF VOLUME OF RUBBER ON STRETCHING.

When rubber is stretched to a relatively high elongation it undergoes fibering and many of its properties change from those of an amorphous to those of a crystalline material. Previous investigators discovered a time lag in the fibering as indicated by a lag in the development of the X-ray diffraction pattern and the double refraction of stretched rubber. In an investigation by W. L. Holt and A. T. McPherson, the same time lag was found by precise measurements of the change of volume on stretching. These results are set forth in RP936 in the November number of the *Journal of Research*.

When rubber containing no coarse fillers was stretched under ordinary circumstances the volume remained constant up to an elongation of 200 or 300 per cent., above which it decreased by an amount which became greater the higher the elongation, the lower the temperature, or the longer the time the rubber was held in the stretched condition. One compound, at an elongation of 600 per cent., showed a decrease in volume of 1.2 per cent. at the end of one minute, while after 3 weeks the decrease in volume was 1.8 per cent. But even at the end of the 3 weeks the volume was decreasing as a linear function of the logarithm of the time, and gave no indication of approaching a limit.

These observations indicate that Poisson's ratio for rubber, in the absence of coarse fillers, is 0.5 or slightly greater, and depends for its precise numerical value upon the elongation, the temperature, and the time after stretching.

METHANOL AS AN ANTI-FREEZE.

The National Bureau of Standards does not recommend any particular material for winter use in automobile radiators but gives in its Letter Circular LC28 information regarding the advantages and disadvantages of various solutions which have been used for this purpose. Since methanol has come into much wider use as an anti-freeze during the past few years, the following information may be of interest.

Methanol can be obtained from the destructive distillation of wood, or made synthetically. Methanol from wood distillation (formerly called wood alcohol) when refined to meet the specification of the Wood Chemical Institute is satisfactory for radiator use, but the crude product may contain free acids as well as ingredients which attack rubber hose. Synthetic methanol is neutral, non-corrosive, and does not attack rubber.

Wood-distillation methanol containing 23 to 24 per cent. of water is commonly marketed as "anti-freeze methanol," and this material gives about the same protection against freezing as denatured alcohol 188° proof. Undiluted synthetic methanol is readily available under several trade names, and three quarts of this product are approximately equivalent to four quarts of denatured alcohol.

Although pure methanol boils at a temperature about 25 degrees Fahrenheit below the boiling point of denatured alcohol, the Bureau has found (*Ind. Eng. Chem.*, **23**, 708; June, 1931) that solutions of the two alcohols which give equal freezing-point protection differ only slightly as to boiling point. There is no evidence that loss of protection due to vaporization is more serious in the case of methanol than in the case of denatured alcohol.

All methanol is poisonous when taken internally, and methanol for anti-freeze use is colored with methyl violet for identification purposes. After investigating possible health hazards in connection with this use of methanol, the U. S. Bureau of Mines concluded (Information Circular IC-6415) that "there is no danger of poisoning from the reasonable use of methanol as an anti-freeze for automobile radiators." Anti-freeze preparations containing methanol bear labels

indicating the approximate percentage in accordance with recommendations of the U. S. Public Health Service.

Most modern anti-freeze preparations contain special corrosion inhibitors. These are of two general types: soluble oils, and inorganic inhibitors such as sodium nitrite or borax. The Bureau has not investigated the proportions in which these rust inhibitors are used, or their relative effectiveness.

SOLUBILITY OF MERCUROUS SULPHATE IN SULPHURIC ACID SOLUTIONS.

As part of a program of research on standard cells, which serve as the primary standard of electromotive force, measurements have been completed recently by D. N. Craig, G. W. Vinal, and F. E. Vinal on the solubility of mercurous sulphate in sulphuric acid solutions. The results, which will be found in the *Journal of Research* for November (RP939), help to interpret some of the conflicting data in the technical literature. They supply for the first time a systematic determination of the effect of temperature on the solubility of this salt.

The determinations were made by an electrolytic method. Each solution was tested after electrolysis for residual mercury. Errors which might arise from the presence of mercuric mercury were shown to be within the limit of experimental error of these determinations. All the solutions were stirred mechanically at fixed temperatures over periods of several days. The concentration of the acid solutions was varied from .001 to 4 molar. The paper gives tables for the solubility of the salt in these solutions, the trend of the curves is discussed, and comparisons are made with data previously obtained by others.

REFRACTIVE INDEX OF DISTILLED WATER AS A FUNCTION OF WAVE-LENGTH.

The validity with which dispersion equations can represent the refractive index of distilled water has been investigated at the Bureau as a preliminary to the use of such equations in adjusting and interpolating experimental data that are being used as a basis for extensive tables of the refractivity of water. For the purposes of these tests measurements were

made at 20.00° C. for 25 different wave-lengths from 3,889 to 7,679 angstroms. All indices were determined by the method of minimum deviation using a water-jacketed hollow prism mounted in a stirred air bath on the table of a spectrometer. Equations having 4, 5, and 6 parameters were used and adjusted by least squares, and some of the difficulties in curve fitting to a few parts per million were investigated.

The results by use of different equations were examined and compared statistically and it is concluded that the Ketteler-Helmholtz equation in the approximate form

$$n^2 = a^2 - k\lambda^2 + \frac{m}{\lambda^2 - l^2}$$

is peculiarly suitable for the purpose of accurately representing the refractivity of water and its variation with wave-length in the visible spectrum.

A paper by Leroy W. Tilton (RP934) in the November number of the *Journal of Research* should be consulted for a more complete account of this work.

COLOR TEMPERATURE OF TUNGSTEN-FILAMENT LAMPS.

When a seasoned incandescent lamp is burned at constant voltage, its chromaticity is not quite constant but changes slowly toward yellow. This chromaticity is conveniently and customariiy specified by color temperature, defined as the temperature which a completely enclosed space, such as in a furnace, would need to have in order to yield the same chromaticity by thermal radiation. The light output of the lamp also decreases.

An investigation was begun in 1930 by Deane B. Judd of the colorimetry section, with the primary purpose of discovering which of a number of types of tungsten-filament incandescent lamps was best suited for standards of color temperature. It was also expected that the study would show how much a working standard could be used before a check against a primary standard was advisable.

As a result of this investigation, which is described in RP937 of the *Journal of Research* for November, 400-watt projection lamps have been chosen as lamp standards of color

temperature; this type of lamp was found to be as permanent as specially built photometric-standard lamps, and it is also a less expensive and more convenient type. The color temperature decreases when seasoned lamps of this type are burned at about 2,850° K. by an average of less than one-tenth of a degree per hour. The rate of decrease is nearly proportional to the twenty-third power of the filament temperature, and is ascribed largely to the accumulation of the familiar brown deposit on the inside of the bulb. The effect of operating unseasoned lamps at constant voltage was found to be a rapid rise in color temperature extending over about half an hour, and amounting to nearly 100° K. at 3,100° K.

THERMAL EXPANSION OF LEAD-ANTIMONY ALLOYS.

RP937 in the November number of the *Journal of Research*, gives the results of an investigation by Peter Hidnert on the linear thermal expansion of cast lead-antimony alloys containing from 2.9 to 98.0 per cent. antimony. Observations were made at various temperatures between − 12 and + 200° C. and are shown in Figs. 3 to 5 of this publication.

The following conclusions were reached:

1. A majority of the curves obtained on cooling lie below the expansion curves obtained on heating. The deviations between these curves are particularly noticeable for the lead-antimony alloys containing up to 15 per cent. antimony which were cast in a preheated steel mold and cooled slowly. The deviations are less noticeable for the alloys of higher antimony content which were cast either in a sand mold or a chill mold. It is probable that the deviations indicate a lack of equilibrium in the samples on account of the effect of the casting conditions or of the chemical composition.

2. The following equations give the relations between the coefficients of expansion and the chemical composition of the lead-antimony alloys investigated.

$$ {}_{20}a_{60} = (29.09 - 0.1789\,\mathrm{Sb})10^{-6} \pm 0.3 \times 10^{-6}, \quad (1) $$

$$ {}_{20}a_{100} = (29.31 - 0.1773\,\mathrm{Sb})10^{-6} \pm 0.6 \times 10^{-6}, \quad (2) $$

$$ {}_{20}a_{200} = (29.08 - 0.1786\,\mathrm{Sb})10^{-6} \pm 0.3 \times 10^{-6}, \quad (3) $$

$$ {}_{100}a_{20} = (29.44 - 0.1826\,\mathrm{Sb})10^{-6} \pm 0.3 \times 10^{-6}, \quad (4) $$

$$ {}_{200}a_{20} = (30.41 - 0.1941\,\mathrm{Sb})10^{-6} \pm 0.3 \times 10^{-6}. \quad (5) $$

In these equations, Sb represents the atomic per cent. of antimony between 4.8 and 97.0 atomic per cent. (2.9 to 95.0 per cent. antimony by weight). In equations (1) to (3) inclusive, ${}_{20}a_{60}$, ${}_{20}a_{100}$ and ${}_{20}a_{200}$ represent the average coefficients of expansion between 20 and 60°, 20 and 100°, and between 20 and 200° C., respectively. In equations (4) and (5), ${}_{100}a_{20}$ and ${}_{200}a_{20}$ represent the average coefficients of contraction between 100 and 20°, and between 200 and 20° C., respectively. The last term in each equation indicates the probable error of the coefficient of expansion. These equations show that the coefficient of expansion decrease linearly with increase in the atomic per cent. of antimony.

3. The densities of the lead-antimony alloys also decrease linearly with increase in the atomic per cent. of antimony.

4. The linear relations between the coefficients of expansion, or density, and the chemical composition (atomic per cent.) are typical of relations for other properties of binary alloys having structures composed of solid solution + eutectic.

5. The coefficients of expansion of the lead-antimony alloys cover a wide range of values. It is possible to select lead-antimony alloys that have approximately the same coefficients of expansion as iron, nickel, gold, copper, silver, aluminum, magnesium and many of their alloys.

SOIL CORROSION STUDIES 1934.

Supplementing the study under the direction of K. H. Logan, on the effect of soils on iron and steel pipe, a large variety of metals and alloys have been exposed to soils where serious corrosion of iron was known to occur. In all, about 9,000 specimens have been buried, 2,500 of which are still in the ground. At about 25 test sites all of the specimens have been removed and for this reason a report on the corrosion of non-ferrous materials underground has been prepared, and will be found in the November *Journal of Research* (RP945).

While in general most of the non-ferrous materials tested corrode less rapidly than does steel in most soils, no one material appears superior to all others under all soil conditions. To obtain the best results the user should determine which material is best adapted to his soil conditions.

The rates of corrosion of each material differ so greatly under different soil conditions that generalizations are of little practical value. In many soils light-weight ferrous materials will last so long that the use of better materials cannot be justified. Under other conditions the value of continuous trouble-free service is sufficient to justify the use of a non-ferrous material.

Soils high in soluble salts which are destructive to steel appear to cause the formation of corrosion products which protect lead from serious corrosion, but in a few soils lead pits badly and there is little evidence of the formation of such a protective coating.

In soils containing sulfides and sulfates, copper and high-copper alloys lose weight rather rapidly, and the protection rendered by the corrosion products is imperfect. Fortunately, the corrosion is nearly uniform. Brasses high in zinc show serious dezincification within a few years when exposed to certain soils. In most soils the corrosion of copper and brass seems to be nearly proportional to the duration of the exposure.

Specimens of zinc were placed in only five corrosive soils. In some of these the zinc corroded rapidly. In three of the soils the rate of penetration tended to increase with the duration of the exposure.

In a few soils aluminum and two of its alloys were unsatisfactory.

Tests in which dissimilar metals were interconnected showed serious acceleration of the corrosion of the anodic metal or alloy under several conditions. Under other conditions no galvanic action was indicated.

Two classes of non-metallic pipe, one of wood fiber and the other of a mixture of Portland cement and asbestos fiber, were not perfectly resistant to several of the soils. However, the methods of manufacture of these materials have been changed since the specimens were submitted.

REDETERMINATION OF THE ATOMIC WEIGHT OF ALUMINUM.

The atomic weight of aluminum has recently been redetermined by James I. Hoffman and G. E. F. Lundell at the

National Bureau of Standards. In this determination of the atomic weight, weighed portions of the metal were converted to the hydroxide and sulphate, respectively. These were then heated until they were changed to the oxide, Al_2O_3, which was finally ignited at 1200 to 1300° C. By this procedure, the atomic weight is related directly to that of oxygen.

Careful analyses showed that the metal contained only very small quantities of impurities and disclosed no gases in the highly ignited oxide. Proper corrections were made for the small amount of impurities in the metal, and special precautions were taken to prevent absorption of moisture by the ignited oxide during weighing.

The value for the atomic weight based on this work is 26.974 ± 0.002.

A complete account of this investigation will be published in the January 1937 number of the *Journal of Research*.

THE FRANKLIN INSTITUTE

STATED MONTHLY MEETING, NOVEMBER 18, 1936.

The regular monthly meeting of The Franklin Institute was called to order at 8:30 o'clock by the President, Mr. Nathan Hayward, who immediately called upon the Secretary for the business of the evening. He reported that the minutes of the previous meeting were published in the Journal for November, and if there were no corrections or additions they should be approved. No objections were heard and the President declared that the minutes were approved. The Secretary also reported that the additions to membership since the last report were as follows: Resident members 5; Student members, 19; Individual members, 3; Museum Student, 32; Family members, 3—a total of 62 new members.

The Secretary called attention to the tenth series of Christmas week lectures to be given in the hall of the Institute on December 28, 29 and 30 by Dr. Robert W. Wood of The Johns Hopkins University. He has selected for his subject "Crystal Magic." Announcement was also made of the special Christmas demonstration in the planetarium and a new lecture entitled "Flight in Nature," which are scheduled to begin soon.

The President then introduced Dr. David Sarnoff, President of the Radio Corporation of America, who delivered an address on "Three Decades of Radio." The speaker reviewed the growth of radio from its beginnings through the years to the time when it was first used as a distress call by transatlantic steamers. Progress was rapid and at the beginning of the World War it had already been so fully developed as to become an instrument of world-wide communication. More recent achievements in broadcasting and the future developments of radio were also considered. The speaker then devoted his attention to the problem of television, which has already gone beyond the experimental stage and will soon come into general use. At the close of the address a vote of thanks was tendered the speaker.

Adjourned.

HENRY BUTLER ALLEN,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, November 11, 1936.)

HALL OF THE COMMITTEE,
PHILADELPHIA, NOVEMBER 11, 1936.

MR. JOHN A. VOGLESON *in the Chair.*

The following report was presented for final action:

No. 3014: Discovery of the Positron.

This report recommended the award of the Elliott Cresson Medal to Dr. Carl

D. Anderson, of Pasadena, California, "In consideration of his discovery of the positron."

The following report was presented for first reading:

No. 3015: Work, of Dr. J. C. Hostetter.

JOHN FRAZER,
Secretary to Committee.

LIBRARY NOTES.

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BOOK REVIEWS.

SIMPLIFIED STRUCTURE FACTOR AND ELECTRON DENSITY FORMULÆ FOR THE 230 SPACE GROUPS OF MATHEMATICAL CRYSTALLOGRAPHY, by Kathleen Lonsdale, D.Sc. 181 pages, 22 × 28.5 cms. London, G. Bell & Sons, Ltd., 1936. Price 10 shillings.

As the title indicates, the contents of this book consist of formulæ. No better explanation can be given than what the author gives in the Foreword. Extracts from this follow.

"In order to analyse the structure of a crystalline substance by methods involving the use of X-rays, a considerable amount of calculation is necessary. If the structure is a complicated one and a three-dimensional map of electron density is required, the calculations may actually take many months to complete. For mathematical tables to be of real assistance in this work, they must be presented in a practical form, suitable for direct use. That has been my aim in regard to these tables of simplified structure factors, now published for the first time. The general structure factor equations included in the 'Internationale Tabellen zur Bestimmung von Kristallstrukturen' (G. Bell and Sons, Ltd., London, 1935) though complete in themselves, cannot be applied without the further simplifications tabulated here."

"As far as the electron density formulæ are concerned, these have been given in a general and condensed form, which can be expanded to suit the particular calculating method or device adopted by the individual worker."

R. H. OPPERMANN.

AN ADVANCED COURSE IN GENERAL COLLEGE PHYSICS, by Paul Leverne Bayley, Ph.D., and Charles Clarence Bidwell, Ph.D. 340 pages, tables, diagrams, 14 × 22.5 cms. New York, The Macmillan Company, 1936. Price $3.50.

This book has been written for the reader who has had a grounding in elementary physics or in mathematics and who desires to progress further along the general line of physics, without specializing in any particular branch. With this purpose in mind, one expects to find and does find the subjects covered similar

to those in the more elementary text. The difference, however, lies in the deeper examination of those subjects which is done in this book. Necessarily, then, mathematics plays a more important role.

There are six divisions of the book—Mechanics, Wave Motion and Sound, Heat, Electricity and Magnetism, Light, and Electron Physics and the Quantum Theory. Each of the above topics is treated in logical order, from the simple to the more complex. And the nature of each topic is given rigorous and complete explanation. For instance, take the very beginning of the book, the chapter on Mechanics. This starts with a discussion on the fundamental concepts of position and motion. Vector operations and their use are described which of course requires the use of trigonometry. Integration is also introduced at once as the inverse of differentiation. Other mathematics is introduced in a way as to gradually make known its usefulness in relation to the completeness of coverage.

The book contains much in the way of illustrations and diagrams. Carefully selected problems are given for solution as exercises. A subject index completes the book.

As a general text, the work is outstanding. It provides a thorough training in fundamental physics and should be of much value to student as well as practicing engineers who have need for more basic knowledge.

R. H. OPPERMANN.

ELECTRICAL ENGINEERING IN RADIOLOGY, A TREATISE ON THE NATURE AND FUNCTION OF ELECTRICAL EQUIPMENT FOR X-RAY WORK IN MEDICINE AND INDUSTRY, by L. G. H. Sarsfield, with foreword by V. E. Pullin. 284 pages, tables, illustrations, 13.5 × 22 cms. Pittsburgh, Instruments Publishing Company, 1936. Price $6.00.

Radiology is a comparatively new science that is now broadening to a great extent, into new fields. The application of electrical engineering to radiology has brought a specialized development with resulting greater efficiency as is evidenced by the progress in design and construction during the last 15 years. Although this volume is devoted to electrical equipment it necessarily makes reference to many of the various components which comprise the complete X-ray range.

The treatment begins with a chapter on X-ray transformers, explaning their construction from the core to the windings, their insulation and position, and terminal bushings. There is here described a transformer of new design, constructed by the Research Department at Woolwich, in which a ring core is employed and the windings are added by through-and-through application of the turns. Then, there follows a chapter on filament transformers.

The employment of uni-directional current by the X-ray tube makes it necessary to provide means for rectification of alternating current. The part of this book devoted to this subject is extremely interesting. First, valve rectification is taken up and a review is made of early rectifiers. From here the subject is brought up to date. Although valve rectification today has such extensive application, there are still unsuccessful application of a large number of mechanical rectifiers. The author has chosen wisely to include in his book explanations of mechanical rectifiers of all descriptions. It is an example of the completeness of the rest of the book.

Other parts of the book are devoted to voltage multiplying circuits and constant potential equipment, electrical measurements, high voltage transmission, control gear, layout and fittings, stages in the progress of the X-ray tube, maintenance, special equipment for various purposes, and a treatment on electrical safety.

The book contains a large number of illustrations, drawings and tables. It undoubtedly satisfies a great need by its complete and clear coverage of such a specialized subject. It is a text for the student, a reference work for the operator, and a very illuminating book for the designer.

R. H. OPPERMANN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 564, Tests of a Wing-Nacelle-Propeller Combination at Several Pitch Settings up to 42°, by Ray Windler. 8 pages, diagrams, 23 × 29 cms. Washington, Superintendent of Documents, 1936. Price ten cents.

A 4-foot model of Navy propeller No. 4412 was tested in conjunction with an N.A.C.A. cowled nacelle mounted ahead of a thick wing in the 20-foot propeller-research tunnel. A range of propeller pitches from 17° to 42° at 0.75R was covered, and for this propeller the efficiency reached a maximum at a pitch setting of 27°; at higher pitches the efficiencies were slightly lower. The corrected propulsive efficiency is shown to be independent of the angle of attack for the high-speed and the climbing ranges of flight. A working chart is presented for the selection of similar propellers over a wide range of airplane speed, engine power, and propeller revolution speed.

Report No. 565, Measurements of Fuel Distribution Within Sprays for Fuel-Injection Engines, by Dana W. Lee. 15 pages, tables, diagrams, 23 × 29 cms. Washington, Superintendent of Documents, 1936. Price ten cents.

Two methods were used to measure fuel distribution within sprays from several types of fuel-injection nozzles. A small tube inserted through the wall of an airtight chamber into which the sprays were injected could be moved about inside the chamber. When the pressure was raised to obtain air densities of 6 and 14 atmospheres, some air was forced through the tube and the fuel that was carried with it was separated by absorbent cotton and weighed. Cross sections of sprays from plain, pintle, multiple-orifice, impinging-jets, centrifugal, lip, slit, and annular-orifice nozzles were investigated, at distances of 1, 3, 5, and 7 inches from the nozzles.

Sprays that were symmetrical about their axes were also tested by a second method in which the injection valve was inserted through the top of a pressure chamber containing a nest of eight concentric cups, the axis of which coincided with the nozzle axis. The injected fuel was caught by the cups, drained into receptacles below, and weighed. Tests were made at 1, 6, and 14 atmospheres, at the same distances from the nozzles used in the first method.

It was found that the distribution of the fuel within the sprays always improved with increasing distance from the nozzle and usually with increasing air density, the effect of both factors being greatest with sprays of high penetrating power. Distribution within sprays from plain nozzles improved slightly with an

increase in the injection pressure or with a decrease in the fuel viscosity. Changing the orifice length-diameter ratio of plain nozzles had little effect on fuel distribution.

Report No. 569, Wing-Nacelle-Propeller Interference for Wings of Various Spans, Force and Pressure-Distribution Tests, by Russell G. Robinson and William H. Herrnstein, Jr. 16 pages, diagrams, 23 × 29 cms. Washington, Superintendent of Documents, 1936. Price ten cents.

An experimental investigation was made in the N.A.C.A. full-scale wind tunnel to determine the effect of wing span on nacelle-propeller characteristics and, reciprocally, the lateral extent of nacelle and propeller influence on a monoplane wing. The results provide a check on the validity of the previous research on nacelles and propellers with 15-foot-span wings tested in the 24-foot wind tunnel and reported in Technical Reports 415, 436, 462, 505, 506, and 507.

The 4/9 scale-propeller and the N.A.C.A. cowling used in the former researches were tested in three typical tractor locations with respect to a thick wing of 5-foot chord and 30-foot span. The span was progressively reduced to 25, 20 and 15 feet and the same characteristics were measured in each case.

The efficiency factors—propulsive efficiency, nacelle drag efficiency, and net efficiency—were obtained for each wing length by means of force tests and the values are compared to determine the effect of span. Pressure-distribution measurements show the lateral extent of the nacelle interference and the propeller-slipstream effect on the span loading for the various conditions. Complete polar curves and curves showing the variation of nacelle drag with lift coefficient are also included.

Force and pressure-distribution tests concur in indicating that, for engineering purposes, the influence of a nacelle and of a propeller, in a usual combination, may be considered to extend laterally on a wing the same maximum distance, or about five nacelle diameters or two propeller diameters outboard of their common axes. All important effects of 4/9-scale nacelle-propeller combinations may be measured within practical limits of accuracy by tests of a 15-foot-span wing.

Report No. 576, Aircraft Accidents—Methods of Analysis, Report prepared by Committee on Aircraft Accidents. 10 pages, diagrams, 23 × 29 cms. Washington, Superintendent of Documents, 1936. Price ten cents.

This report is a revision of Technical Report No. 357, prepared by the Committee on Aircraft Accidents and published in 1930. The original report of the National Advisory Committee for Aeronautics on the analysis of aircraft accidents, of which Report No. 357 was the first revision, was prepared by a Special Committee on the Nomenclature, Subdivision, and Classification of Aircraft Accidents, and issued as Technical Report No. 308 of the National Advisory Committee for Aeronautics. The special committee was organized by the National Advisory Committee for Aeronautics in response to a request dated February 18, 1928, from the Air Coördination Committee which consisted of the Assistant Secretaries for Aeronautics in the Departments of War, Navy, and Commerce.

Since the publication of the original report, the practical value of the method of accident analysis has been definitely proved by its use in the War, Navy, and Commerce Departments. However, during the first two years questions of interpretation of some of the definitions arose and incidents occurred for which the

specified classifications seemed inadequate. In order to meet these conditions, Report No. 357 was prepared by the Committee on Aircraft Accidents. The recent rapid advances in aeronautics have resulted in the need for further revision, and this report has accordingly been prepared to supersede Report No. 357.

THE SCIENTIFIC BASIS OF ILLUMINATING ENGINEERING, by Parry Moon. 608 pages, tables, illustrations, 15.5 × 23.5 cms. New York and London, McGraw-Hill Book Company, Inc., 1936. Price $5.00.

The most important of our senses is sight and it seems strange that so little attention is paid to it, particularly from a scientific standpoint. There is much advertising and other publicity bombarding the average man today on the subject of better illumination and the deleterious effects of poor illumination, and it is well to see increasing evidences of cases where artificial illumination is taken seriously or as a profession even though they are comparatively few in number. That illuminating engineering is destined to become a profession there is little doubt. As such, a proper scientific basis must be formed upon which the superstructure can be built. Now, here is a book for that very purpose. Its contents are confined to the material which will be of greatest use in an introductory course in illuminating engineering—the scientific basis of the subject—a development of a suitable foundation of applied physics.

An introductory chapter explains some of the fundamentals of the subject such as the nature of radiation, and wave-length and frequency. This is followed by treatments on the spectroradiometric curve upon which the book is based instead of the standard candle, radiation from gaseous conduction and incandescent sources, the measurement of light, illumination from point and surface sources, lighting design, and color. Developments such as the barrier-layer photoelectric cell, the sodium lamp, and the high pressure mercury lamp are included. The author states in outright manner in the preface that no attempt is made to treat the whole field of illuminating engineering, therefore practical applications, artistic aspects, and psychological effects are hardly touched.

The book is well constructed, the subjects presented in logical order and in a clear and well illustrated manner. It is flexible in that certain portions can be omitted or included to accommodate specific coverage. A bibliography follows each chapter for further reading. Tables, curves and diagrams given in the text and data in the appendix furnish valuable reference material.

To those who desire to follow illuminating engineering as a profession and therefore desire a sound technical basis from which it may be possible to exercise originality for development beyond present methods, this book should be of value.

R. H. OPPERMANN.

PUBLICATIONS RECEIVED.

Recent Advances in General Chemistry, by Samuel Glasstone. 430 pages, tables, illustrations, 14 × 21 cms. Philadelphia, P. Blakiston's Son & Co., Inc., 1936.

Recent Advances in Physical Chemistry, by Samuel Glasstone. 477 pages, tables, illustrations, 14 × 21 cms. Philadelphia, P. Blakiston's Son & Co., Inc., 1936.

Electrical Engineers' Handbook, volume 4, Electric Power, prepared under the editorship of Harold Pender, William A. Del Mar and Knox McIlwain. Variously paged, tables, 14 × 22 cms. Price $6.00. Volume 5, Electrical Communication and Electronics, prepared by a staff of specialists under the editorship of Harold Pender and Knox McIlwain. Variously paged, tables, 14 × 22 cms. New York, John Wiley & Sons, Inc., London: Chapman & Hall, Ltd., 1936. Price $5.00.

A Textbook of Organic Chemistry for Students of the Medical Sciences, by Hugh C. Muldoon. 590 pages, illustrations, 14 × 21 cms. Philadelphia, P. Blakiston's Son & Co., Inc. Price $3.00.

A Survey Course in Physics, by Carl F. Eyring. 378 pages, illustrations, 16 × 23 cms. New York, Prentice-Hall, Inc., 1936. Price $3.00.

The Story of Human Error, edited by Joseph Jastrow. 444 pages, tables, 16 × 23 cms. New York and London, D. Appleton-Century Company, Inc., 1936. Price $3.50.

Transactions of the American Institute of Mining and Metallurgical Engineers, vol. 120, Iron and Steel Division. 411 pages, illustrations, 16 × 24 cms. New York, Institute, 1936.

Lessons and Problems in Electricity, by Newell C. Page. 356 pages, tables, diagrams, 14.5 × 22 cms. New York, The Macmillan Company, 1936. Price $2.75.

Aluminum Paint and Powder, by Junius David Edwards. 216 pages, illustrations, tables, 16 × 23.5 cms. New York, Reinhold Publishing Corp., 1936. Price $4.50.

The Scientific Basis of Illuminating Engineering, by Parry Moon. 608 pages, tables, illustrations, 15.5 × 23.5 cms. New York and London, McGraw-Hill Book Company, Inc., 1936. Price $5.00.

Kent's Mechanical Engineers' Handbook, II, Power, eleventh edition, rewritten by Robert Thurston Kent. Variously paged, 14 × 22 cms. New York, John Wiley & Sons, Inc. London: Chapman & Hall, Ltd., 1936. Price $5.00.

Elements of Nuclear Physics, by Franco Rasetti. 327 pages, tables, 15.5 × 23.5 cms. New York, Prentice-Hall, Inc., 1936. Price $4.50.

Radio Field Service Data, by Alfred A. Ghirardi. Unpaged, loose-leaf, illustrations, 14 × 21 cms. New York, Radio and Technical Publishing Co., 1936.

Einführung in die klassische Elektrodynamik, von Dr. Johannes Fischer. 199 pages, illustrations, 17.5 × 26 cms. Berlin, Julius Springer, 1936. Price 12 marks.

Elektronentheorie der Metalle, von Dr. Herbert Frohlich. 382 pages, illustrations, 15 × 22 cms. Berlin, Julius Springer, 1936. Price 27 marks.

Werkstoffkunde der Hochvakuumtechnik, von W. Espe und M. Knoll. 383 pages, illustrations, tables, 17 × 25 cms. Berlin, Julius Springer, 1936. Price 48 marks.

Canada Dominion Bureau of Statistics, Report on the Grain Trade of Canada, 1935. 202 pages, tables, 16.5 × 24.5 cms. Ottawa, King's Printer, 1936. Price fifty cents.

National Advisory Committee for Aeronautics, Twenty-first Annual Report, 1935. 625 pages, tables, illustrations, 23 × 30 cms. Technical Notes, No. 580, A General Tank Test of a Model of the Hull of the British Singapore IIC Flying Boat, by John R. Dawson and Starr Truscott, 11 pages, diagrams. No. 582, Analysis and Model Tests of Autogiro Jump Take-Off, by John B. Wheatley and

Carlton Bioletti, 18 pages, tables, illustrations. No. 583, Mixture Distribution in a Single-Row Radial Engine, by Harold C. Gerrish and Fred Voss, 7 pages, diagrams. 3 pamphlets, 20 × 26 cms. Washington, Committee, 1936.

Bell Telephone Laboratories, Monographs: B-934, Fields Caused by Remote Thunderstorms, by K. E. Gould, 19 pages, maps. B-936, Tandem Operations in the Bell System, by F. M. Bronson, 25 pages, illustrations. B-939, Oscillations in Systems with Non-Linear Reactance, by R. V. L. Hartley, 17 pages, diagrams. B-943, A New Type of Underground Telephone Wire, by D. A. Quarles, 9 pages, illustrations. B-946, Gutta-Percha Effect of Vulcanization on Its X-Ray Diagram, by C. S. Fuller, 14 pages, tables, diagrams. B-947, Soft Vulcanized Rubber—Effect of Temperature and Oxygen Pressure on Aging, by J. H. Ingmanson and A. R. Kemp, 10 pages, tables, illustrations. B-948, Field Currents From Tungsten and Thoriated Tungsten, by A. J. Ahearn, 16 pages, diagrams. B-949, Change of Pitch with Loudness at Low Frequencies, by William B. Snow, 6 pages, diagrams. B-950, A Laboratory Vacuum Casting Furnace, by Jack H. Scaff and Earle E. Schumacher, 6 pages, diagrams. B-951, The Optical Constants of Potassium, by Herbert E. Ives and H. B. Briggs, 9 pages, illustrations. B-952, Calculated and Experimental Photoelectric Emission from Potassium, by Herbert E. Ives and H. B. Briggs, 4 pages, tables. B-953, Acoustics of Sound Recording and Reproduction from Motion Pictures, by Franklin L. Hunt, 6 pages. 12 pamphlets, 15 × 23 cms. New York, Bell Laboratories, 1936.

Lord Kelvin, Master of Heat and Cold. 7 pages, 15 × 23 cms. New York, Temperature Research Foundation of Kelvinator Corporation, 1936.

The Wonderful Achievements of Radiotelegraphy in War and Peace. 30 pages, 14 × 21 cms. New York, William Dubilier, 1919.

CURRENT TOPICS.

Unusual Transformer.—(*Power*, Vol. 80, No. 10.) A transformer just completed at the G. E. Pittsfield Works for Consolidated Gas & Electric Co., Baltimore, Md., has its cooling radiators arranged in three large banks to facilitate installation. Motor driven blowers provided for each bank are arranged for manual control, or can be started or stopped automatically by changes in oil temperature. The transformer is rated 53,330 kva. with the blowers, and 40,000 kva., without them. Total weight including oil is 400,000 lb., of which 34,000 lb. is in the copper wire. It stands 24½ ft. high and covers a floor area of 31½ × 41⅛ ft. Load-ratio control equipment is provided, affording different ratios of transformation and providing great flexibility in control of voltage and system power factor.

R. H. O.

Foreign Steam Plant Uses New Principle.—(*Electrical World*, October 10, 1936.) The I. G. Farbenindustrie has just completed a new type of steam plant at Leverkusen, Germany, which will produce electricity at $0.002 per kilowatt-hour, according to information received in this country. This plant, rated at 250,000 hp., is said to be the only one of its kind in the world. It has a vertical boiler with tubes between 75 and 100 ft. long. The principal feature of the plant is that there is no water in the fire box. The tubes, instead of water, contain steam, which is drawn off the head of the tubes at 1,000 lb. It is said that in no other plant in the world is steam pumped at such pressure. The boiler burns powdered coal at a temperature of 500 deg. C., working pressure 135 atmospheres. It is equipped with Cottrell precipitators and has no smokestacks. There is no fly ash and it gives off no combustible matter.

R. H. O.

Russia Plans Huge Network of Heat, Power Stations.—(*Heating and Ventilating*, Vol. XXXIII, No. 10.) The third Five-Year Plan will see development on a large scale of district power stations which supply not only electricity, but hot water for domestic and industrial heating purposes. The water will be obtained by utilizing the steam from the turbines on the way to the condenser, a valuable source of energy. The plans raise a number of technical problems

which are dealt with in a recent issue of *Za Industrializatsiu*, organ of the Peoples Commissariat of Heavy Industry. One of these is the transportation and storage of fuel for large heat and power stations. Large quantities must be transported and such traffic could not be brought into the center of large cities. Such difficulties could be overcome by burning gas instead of solid fuel. Both Leningrad and Moscow have fairly close at hand low quality fuels which could be gasified and transported through pipes to power stations. True, such gasification is expensive and would require large capital outlay. But for Leningrad and Moscow, considerations of hygiene, transport and convenience may outweigh the cheapness of burning the fuels directly under the boilers. Natural gas also promises to be a great source of fuel. Intensive work is also being carried out to utilize another potential source—underground gasification of coal. This is being accomplished already on a small scale.

R. H. O.

Researchers Find New Coal Tar Products.—(*National Petroleum News*, Vol. XXVIII, No. 42.) A new series of high-boiling solvent oils and a new stable resin have been prepared from light oils derived from by-product coking operations. This work has been done by P. J. Wilson, Jr., and J. H. Wells, at Mellon Institute of Industrial research. These high-boiling oils are mainly aromatic in character, with small percentages of paraffins and of oils soluble in 80 per cent. sulfuric acid. They boil between 180° C. and 375° C., have a specific gravity of 0.950 to 1.030, and are excellent solvents for resinates, many natural gums and synthetic resins, rubber, Thiokol, etc. The resin appears to be a mixed polymer of aromatic olefins and cyclic dienes, or compounds containing two separate double bonds between carbons. It is emulsifiable in water, soft at 140° C., contains no free carbon, and is miscible with many gums, resins and asphalt, coal tar pitch, and pine tar. It appears to be suitable for binder and adhesive purposes, floor tile, varnishes, linoleum, battery seals, etc.

R. H. O.

No Weather Effect from Lake Mead.—(*Engineering News Rec.*, Vol. 117, No. 17.) Lake Mead, which is the lake formed by Boulder Dam, has been the subject of a number of inquiries with relation to it being a source of precipitation on the surrounding usually dry country. This precipitation, according to calculations made by J. Cecil Alter meterologist for the United States Weather Bureau, is negligible. Mr. Alter concluded that "Utah received in precipita-

tion during the last twelve months 100 times as much water as could possibly have been evaporated from Lake Mead, and during August 1936, received 150 times as much rain as could have come from the artificial lake. I doubt whether Utah received more than a few drops of rain from the Boulder Dam area. Moisture rising as vapor under ordinary conditions is diffused rapidly, and frequently travels 25 miles an hour, or 600 miles per day." Mr. Alter stated that more than normal precipitation occurred in Utah in January, February, June, July and August 1936, with February and July the wettest on record. However, in March, April, May and September 1936, the precipitation has been below normal. These variations, Mr. Alter said, were no more than would be normally expected.

R. H. O.

La Mont Controlled Forced Circulation Steam Generator.—(*Engineering*, Vol. CXLII, No. 3692.) Several designs of forced circulation boilers have appeared of late and Messers La Mont Steam Generator, Ltd., have developed a waste heat steam generator for water gas plants and a furnace water wall for marine boilers. The present design, however, differs substantially from both of these. The boiler is of water tube type and has a steam drum. There are no water drums, the "return" flow being connected with the suction side of the centrifugal pump which circulates the water. This circulation is not a mere delivery of water to the tubes generally, but is so controlled that each tube receives the amount of water appropriate to its steam generating capacity, this capacity being determined by the position of the tube in the boiler. Any desired direction of the flow in relation to the gas stream etc. is, further, possible. It is claimed that the accurate correlation of water flow and rate of heat absorption eliminates the possibility of overheating which may arise from the unstable conditions at times associated with natural circulation, that corrosion is avoided, and that scale-forming or suspended matter cannot settle on the heated tube wall but is carried to the drum, the lower part of which contains water, and is there deposited to be removed by blowing down in the usual manner. The boiler can, in consequence, be steamed at very high rates of evaporation. It follows from the individual control of the water flow in each tube that the heating surface can be disposed without loss of efficiency in any convenient manner and therefore the form of the boiler is not stereotyped.

R. H. O.

Heat the Floor to Warm the Air.—(*Electrical World*, Vol. 106, No. 43.) Revolutionary is the method of warming large-area

buildings developed at the new hangar to the Douglas aircraft factory at Santa Monica, Calif. Efficient and economical heating arrangements for such large inclosures have long been a problem and the Douglas engineers decided that the best means of providing comfortable working conditions was actually to use the concrete floor slab as a source of heat. To accomplish this novel electrical heating, units consisting of nichrome wire pulled in Fretz-Moon conduit and insulated therefrom by means of porcelain spacers, were developed. Units are of sufficient capacity to provide the most economical electrical distribution over the 300 by 300 ft. area of the hangar. The units are laid in the form of loops on 3 ft. centers so that they will be in the center of a 2 in. slab of concrete when the floor is poured. Calculated to raise the temperature of the concrete floor slab to 90 deg. F., the energy is supplied to the units at off-peak periods, thereby enabling a very favorable rate for power to be obtained. The concrete itself retains the heat for a long period, so that advantage can be taken of this method of supply.

R. H. O.

Surgical Supply Company Uses Air Conditioning.—(*Refrigerating Engineering*, Vol. 32, No. 5.) The E. F. Mahandy Surgical Supply Co. of Boston, Mass., recently decided to employ air conditioning in the handling of their suture product in order to produce an atmosphere as nearly sterile as mechanically possible. This problem entailed a very special and unique application of air conditioning. It is a combination of industrial and comfort cooling with emphasis stressed upon the introduction of clean air as free from contamination as mechanically feasible. The unit housing the various operations was built within a large room. The new structure was divided into several small rooms with the refrigerating and air handling equipment in a separate room. The raw suture material is first brought into the non-sterile room where it undergoes mechanical preparation and is finally inserted into tubes. The racked tubes are then passed into the sterilizing room and placed into the sterilizer. Then in another room alcohol is added to the tubes and they pass into the sealing room where they are sealed and packed for the market. The bacteriological testing laboratory is located adjacent to the sealing room and it is here where the story of the application of air conditioning has been written indelibly. Since the beginning of these operations under the influence of air conditioning, the company has not lost one tube of suture due to contamination. A culture test was taken within the air conditioned sterile room during a period when the room was occupied and work

going on. In this case, the agar plate was exposed for a half an hour, and at the end of incubation there were only two colonies of bacteria on the agar plate. This is truly a remarkable testimonial for this particular application of air conditioning.

R. H. O.

Pneumatic-Tired Carriers Transport Heavy Girders on Earth Roadway.—(*Construction Methods*, October, 1936.) Riding on a dozen pneumatic tires, distributed four under the rear end of a truck tractor and eight under a specially designed trailer, 65 ton girders for the Little Hell Gate spans of the Triborough Bridge, New York City, traveled in wet and dry weather over an earth road and down a steep grade to the water's edge where a derrick on the bridge deck picked them up and set them in the structure. Both trucks and trailers were equipped with adjustable welded brackets for transporting the girders in vertical position. Each of the four trailers constructed weighs about 19 tons and consists of a heavy welded frame resting on two trunnion-type rocker axles equipped with dual wheels making four dual wheels in all. These wheels are arranged in a straight line across the width of the trailer. The axles could rotate through a limited angle in a vertical plane but could not be turned in a horizontal plane. Free rocker motion of the axles assured full load carrying effectiveness of the dual wheels on uneven ground. Each wheel was shod with a 10.50 × 24 in. pneumatic tire. Only about one-fourth of the weight of the girder was thrown on the truck, the remainder being carried by the trailer, which was spotted near the five-eighths point of the girder to obtain this load distribution.

R. H. O.

Oranges, Coffee, Bacon and Logs.—H. W. YOUNG (*Industry and Welding*, Third Quarter, 1936). In a steadily increasing number of localities today, you may go into the corner grocery or the down-town department store and see a neat array of cartons of a little over a cubic foot in contents which contain something called Pres-to-logs. These logs are briquettes of the dry waste in the form of sawdust, shavings and hogged chips from lumber manufacturing plants. They can be used in the ordinary wood or cook stove or combination range, or possibly in the fireplace. Research and experiments in the development of this product on the part of Wood Briquettes Inc., began in February 1929 and after four years a machine was built that would operate satisfactorily. To carry the operation through and control it uniformly led finally to the adoption of a machine having the screw principle of feeding and pressing the material, working against a pressure holding cylinder. It

consists of a series of dies held in a large wheel or disc. As this revolves a step at a time, each die is lined up automatically with the screw cylinder opening and receives the material from the screw and its extension head. All the material is reduced from its original state by grinding to a uniform size. Tremendous friction is developed in filling a die, creating temperatures of from 350 to 450 deg. F. Therefore the die holding disc is water cooled. As each die is filled, the wheel turns one step and brings the next die into position to be filled. As the material for each log is forced into the die by the screw, it forces the previous log, now cooled, out at the other end. The logs are of uniform size and density. Each log weighs about 8 lbs. This condensed form of fuel compares favorably with other classes of fuel.

R. H. O.

New York's First Glass Office Building.—(*Skyscraper Management*, Vol. 21, No. 10.) At the southwest corner of Fifth Avenue and Fifty-sixth Street a business building built entirely of glass construction, even to the floors, is to be constructed for the Corning Glass Works. The building will be five stories high. The facade will be built of glass blocks, each one foot square, separated by seams of lime, Portland cement, and mortar one-quarter inch wide. These great screens of glass will be set in a frame of Indiana limestone, the only stone in the building visible to the public. As the entrance to the building will be on the side street, the entire Fifth Avenue frontage will be a pile of translucent glass. The strength of this glass house was illustrated recently by Arthur A. Houghton, Jr., an officer of the Corning Glass Works, who said that a wall of these blocks could be constructed 600 feet before the base would show the effect of the tremendous weight. The building will be sealed, so to speak. It will be air-conditioned and the face of the completed structure may be washed with a hose, dust and grime coming off as if it were a mirror. The most important physical characteristic of the glass is its coefficient of expansion—.0000032 for each degree of temperature change between 66 degrees and 662 degrees F. This characteristic is considered extremely important because of severe and sudden changes to which materials used in building exteriors are subjected. The scientifically designed optical fluting is pressed on the inner walls of the block. The flutes run vertically on one wall and horizontally on the opposite. Although all images seen through the block are thus purposely obscured, 78 per cent. of the light directed at the surface will be transmitted.

R. H. O.

Television.—In a statement made November 6, 1936, DAVID SARNOFF, President of the Radio Corporation of America, explained that definite progress in research and development has been made in practical television. Transmissions have been made from the top of the Empire State Building in New York City. Observations and measurements of these have been made through experimental receivers in the metropolitan area. There have been successfully transmitted through the air, motion pictures as well as talent before the televisor. The distance over which these television programs have been received has exceeded expectations. A great deal has been learned about the behavior of ultra short waves and interferences, and the soundness of the technical fundamentals of the R.C.A. system has been confirmed. A 343-line definition is used in field tests and a 441-line definition has been recommended. Mr. Sarnoff states that from the standpoint of research, laboratory development, and technical demonstration, television progress in the United States continues to give us an unquestioned position of leadership in the development of the art. Further, "the distinction between television in this country and abroad is the distinction between experimental public services undertaken under government subsidy in countries of vastly smaller extent, and the progressive stages of commercial development undertaken by the free initiative, enterprise and capital of those who have pioneered the art in the United States. While the problems of television are formidable, I firmly believe they will be solved. With the establishment of a television service to the public which will supplement and not supplant the present service of broadcasting, a new industry and new opportunities will have been created."

R. H. O.

Efficient Luminescent Materials.—MR. H. W. LEVERENZ of the Radio Corporation of America presented a paper before a joint meeting of the American Physical Society and the Optical Society of America that revealed very interesting information on the creation of more efficient luminescent materials, which was a problem in the development of improved television receivers. From the paper it was apparent that the laboratory work necessitated delving into pure scientific research. It was found that materials made to a certain formula on one day would give a widely different performance on another day. A suspected reason for this was a slight variation of the dust content of the air. Special laboratories were built and air-conditioned for the further investigation. One curious bit of knowledge which this research has turned up is that the absolute purity of materials used in experimenting

does not necessarily make for the most efficient results in their use in cathode ray tubes. It is, however, highly important to be able to control very accurately the addition of any foreign or "impure" substances which make the luminescent material produce more light in the tubes.

R. H. O.

New Corrosion Resistant Specialties.—The International Nickel Co., Inc. has announced two new products to meet corrosive problems in a variety of plants where acid, alkali and other corrosive agents are encountered. One is a Monel caster for trucks, hampers and wheeled conveyors of all kinds used where corrosive materials are liable to spill over on the floor. The other is for use in similar plants and is a Monel pail of 12, 14, and 16 quart sizes. Bottom and sides are electrically seam welded. The seam cannot break open and there are no rivets at which leaks can start.

R. H. O.

International Association for Testing Materials.—Arrangements are being made for the Second International Congress of this association to be held in London, England, April 19–24, 1937. The subjects selected for discussion are divided into four groups dealing respectively with Metals, Inorganic Materials, Organic Materials, and Subjects of General Importance. The latter include the relation between the results of laboratory tests and behavior in use and service, the bearing of recent advances in physics and chemistry on the knowledge of materials, and the properties of materials for the thermal and acoustic insulation of buildings.

R. H. O.

Fifth International Congress for Applied Mechancis (1938).—Announcement is made by the American Committee of the meeting in Cambridge, Mass., U. S. A., September 12–16, 1938, at Harvard University and the Massachusetts Institute of Technology. As in the past, this Congress is to be a meeting of persons working in the field of Applied Mechanics before whom reports of work may be presented for discussion. The program will cover structures, elasticity, plasticity, hydro- and aerodynamics, meterology, heat transfer, dynamics of solids, vibration and sound, etc.

R. H. O.

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